1831 1959

THE ADVANCEMENT OF SCIENCE

VOL. XVI NO. 62 SEPTEMBER 1959

Editorial Committee
Dr. H. HAMSHAW THOMAS, M.B.E., F.R.S. (*Chairman*)
Prof. L. DUDLEY STAMP, C.B.E., Dr. W. E. SWINTON

CONTENTS

Addresses delivered at the Annual Meeting of the British Association for the Advancement of Science in York, September 2 to 9, 1959

PAGE

PORTRAITS OF THE PRESIDENT OF THE ASSOCIATION AND OF PRESIDENTS OF SECTIONS . . . . . *frontispiece*
OFFICERS AND COUNCIL 2
THE PROPER STUDY OF MANKIND IS MAN, *by* Sir James Gray, C.B.E., M.C., F.R.S. 3
THE VISUALIZATION OF MAGNETIC PROCESSES, *by* Prof. L. F. Bates, F.R.S. . 13
MEDICAL ASPECTS OF CARBOHYDRATES, *by* Prof. M. Stacey, F.R.S. . . 23
RECENT DEVELOPMENTS AND TRENDS IN PALAEONTOLOGY, *by* Prof. O. M. B. Bulman, F.R.S. 33
MAN AND THE WORLD'S FAUNA, *by* Dr. L. Harrison Matthews, F.R.S. . 43
TRENDS IN URBAN EXPANSION, *by* Prof. K. C. Edwards 55
HOW MUCH SCIENCE? *by* Prof. John Jewkes, C.B.E. 67
THE CRITICAL IMPORTANCE OF TRANSPORT AND COMMUNICATIONS, *by* Sir Ewart Smith, F.R.S. 81
THE NATURE AND SCOPE OF ARCHAEOLOGY, *by* Prof. Ian A. Richmond, C.B.E. 95
ARTIFICIAL ORGANS: BIOLOGICAL APPLICATIONS, *by* Prof. A. Hemingway . 102
PERCEPTION, ATTENTION AND CONSCIOUSNESS, *by* Prof. Magdalen D. Vernon 111
PLANTS ON LAND AND IN THE OCEANS, *by* Dr. W. R. G. Atkins, C.B.E., O.B.E. (Mil.), F.R.S. 124
WHAT ARE OUR SCHOOLS FOR? *by* Sir James J. Robertson, O.B.E. . . 136
BALANCE IN BRITISH FARMING, *by* Dr. H. G. Sanders 145

"X-rays" by Roy Nockolds

The Inquiring Rays

The value of medical X-rays in diagnosis is incalculable. Over 25,000,000 pictures are made every year, each revealing to expert eyes otherwise hidden internal conditions.

Elaborate precautions are taken to ensure that patients and staff suffer no ill effects. Apparatus and X-ray tubes are designed to prevent unwanted radiation exceeding the recommendations of the International Commission on Radiological Protection.

Even so, continuous research is undertaken to widen the safety margin still further. From the Mullard Laboratories there now comes an outstanding development in the shape of two new X-ray tubes which reduce 'off-beam' radiation to only one-tenth of the recommended maximum level. This is far below that of previous tubes, so low, in fact, as to be a quite insignificant component of X-ray dosage.

These 'Guardian' tubes, as they are known are as efficient as they are safe. They are new and powerful weapons in man's unceasing fight against disease.

Technical Information Services

Mullard Technical Information Services cover almost every field of electronics. If you have an applications problem, write to the address below.

Mullard *Progress in Electronics*

Mullard Mullard Limited, Technical Information Services, Mullard House, Torrington Place, London, W.C.1

MP 549

OFFICERS AND COUNCIL OF THE BRITISH ASSOCIATION, 1959

PATRON

HER MAJESTY THE QUEEN

PRESIDENT, 1959

SIR JAMES GRAY, C.B.E., M.C., F.R.S.

PRESIDENT-ELECT

SIR GEORGE THOMSON, F.R.S.

GENERAL TREASURER

LORD RENNELL OF RODD, K.B.E., C.B.

GENERAL SECRETARIES

DAME KATHLEEN LONSDALE, D.B.E. F.R.S. — Dr. W. E. SWINTON

ORDINARY MEMBERS OF THE COUNCIL

Dr. D. A. ALLAN, C.B.E.
J. N. L. BAKER
Prof. R. J. BROCKLEHURST
Dr. H. O. BULL
Prof. W. BURNS
P. RITCHIE CALDER, C.B.E.
Prof. G. R. CLEMO, F.R.S.
Prof. P. SARGANT FLORENCE, C.B.E.
Prof. T. N. GEORGE
Sir RONALD GOULD
Prof. L. HUNTER
Rev. Prof. E. O. JAMES
Prof. D. L. LINTON
JAMES MACDONALD, C.B.E.
Dr. D. C. MARTIN
Dr. B. J. MASON
Dr. H. G. MAULE
L. R. MISSEN, C.M.G., M.C.
Lord NETHERTHORPE
Dr. K. P. OAKLEY, F.B.A.
Dr. R. W. POWELL
Dr. H. G. SANDERS
Prof. O. A. SAUNDERS, F R.S.
Dr. R. E. SLADE
Sir EWART SMITH, F.R.S.
Dr. C. J. STUBBLEFIELD, F.R.S.
Dr. W. B. TURRILL, C.B.E., F.R.S.
Prof. G. C. VARLEY
Dr. N. A. B. WILSON
Prof. T. WILSON, O.B.E.

EX-OFFICIO MEMBERS OF THE COUNCIL

Past-Presidents of the Association, the President for the year, the President and Vice-Presidents for the ensuing Annual Meeting, past and present General Treasurers and General Secretaries, and the Local Treasurers and Local Secretaries for the Annual Meetings immediately past and ensuing.

PAST PRESIDENTS OF THE ASSOCIATION

H.R.H. THE DUKE OF WINDSOR, K.G., F.R.S. (1926)
Sir HENRY DALE, O.M., G.B.E., F.R.S. (1947)
Sir JOHN RUSSELL, O.B.E., F.R.S. (1949)
Sir HAROLD HARTLEY, G.C.V.O., C.B.E., M.C., F.R.S. (1950)
H.R.H. THE PRINCE PHILIP, DUKE OF EDINBURGH, K.G., K.T., C.B.E., F.R.S. (1951)
Prof. A. V. HILL, C.H., O.B.E., F.R.S. (1952)
Sir EDWARD APPLETON, G.B.E., K.C.B., F.R.S. (1953)
The Lord ADRIAN, O.M., F.R.S. (1954)
Sir ROBERT ROBINSON, O.M., F.R.S. (1955)
Sir RAYMOND PRIESTLEY, M.C. (1956)
Prof. P. M. S. BLACKETT, F.R.S. (1957)
Sir ALEXANDER FLECK, K.B.E., F.R.S. (1958)

PAST GENERAL OFFICERS OF THE ASSOCIATION

M. G. BENNETT
Prof. P. G. H. BOSWELL, F.R.S.
Prof. Sir DAVID BRUNT, F.R.S.
Sir HAROLD HARTLEY, G.C.V.O., C.B.E., M.C., F.R.S.
Dr. EDWARD HINDLE, F.R.S.
Sir BEN LOCKSPEISER, K.C.B., F.R.S.
Sir FRANK SMITH, G.C.B., G.B.E., F.R.S.
Sir RICHARD SOUTHWELL, F.R.S.
Prof. F. J. M. STRATTON, O.B.E., F.R.S.
Dr. G. TAYLOR
Dr. N. C. WRIGHT, C.B.

HONORARY AUDITORS

Dr. D. B. HARDEN, O.B.E. — Dr. H. G. MAULE

SECRETARY

Sir GEORGE V. ALLEN, C.B.E.

Poodles, puddles and plastics

Protection from the weather is but one very minor contribution of plastics to the greater personal comfort of men, women and lucky dogs. But we must start somewhere . . .

In a few short years these gay, lightweight materials, with their quick-clean, corrosion-resistant surfaces, their unsuspected strength and astonishing manufacturing versatility have become part and parcel of domestic and industrial life. Already we find ourselves taking them for granted, yet their potentialities are still far from fully explored.

Shell have invested, and will continue to invest, large sums in plastics research and development. At Carrington, Shell chemists are now producing a new high-density polyethylene, stiffer and stronger than conventional polyethylene. In addition to 'Carlona' polyethylenes, 'Carina' P.V.C.'s and 'Carinex' polystyrenes, Shell output includes solvents, intermediates and other chemicals important in plastics manufacture.

Whatever the needs of industry for plastic raw materials, Shell can almost certainly supply them. In fact, if you have any problems concerning the use of chemicals, industrial or agricultural, Shell may well be able to help. You can easily find out.

Write to the Sales Promotion Manager, Shell Chemical Company Limited, Marlborough House, 15-17, Gt. Marlborough Street, London, W.1.

YOU CAN BE SURE OF SHELL CHEMICALS

SHELL

THE PROPER STUDY OF MANKIND IS MAN[1]

ADDRESS BY SIR JAMES GRAY, C.B.E., M.C., F.R.S.
PRESIDENT OF THE ASSOCIATION

I

DURING the course of years the need for a wider social outlook on Science has been reflected by two important extensions in the range of the Association's interests. It now includes the social as well as the natural and mechanical sciences: and it is more and more concerned with the dissemination of scientific knowledge to the whole community. But the wider the field and the larger the audience, the more difficult the task of presentation becomes. Scientists find it more and more difficult to keep abreast of all the main lines of development even within their own subjects; we become more and more specialised and less and less able to see the wood for the trees. Indeed, it might be said that one of the Association's most important functions is to bridge the gaps between our different Sections. In addressing the Association, a President has to decide whether to speak as a specialist or, by straying into unfamiliar fields, run the risk of scientific, economic or political criticism.[2] Perhaps rashly, I have chosen to face this danger, by trying to look at Man from a biological point of view and to suggest how the picture might—here and there—merge into a humanitarian background. Hence the title of my Address. But before doing so I would like to touch on two quite general topics.

Firstly, one of the most important aspects of modern science is its repercussion on international relationships, and when it begins to threaten the existence of the whole human race, it really does seem to be going just a step too far. There will always be danger and appalling waste of human effort until individual nations can be persuaded, or are forced, to think in terms of the welfare of humanity as a whole. It is not our job to suggest how this might best be achieved by moral or political agreement. A scientific approach must be completely dispassionate, but we shall not make much impression on public opinion so long as men's minds are biased by fear and suspicion; frightened or angry politicians, like frightened or angry animals, cannot be trusted to react wisely. There is not the slightest doubt, however, that the discoveries of physics *have* frightened mankind and that there are far too many intelligent people looking askance at Science and wondering where it is leading them. In trying to link Science to the humanities our primary objective should be to depict Man's position in the world of Nature as a source—not of fear or doubt, but of courage and inspiration.

Our second main objective should be to demonstrate the place of Science in a general philosophy of life. To be of real value, such a philosophy must rest on knowledge and experience which has already proved acceptable over a very wide range of local environments and national interests, and it must, at the same time, be closely concerned with problems of everyday life. In these respects Science is unique. Except when subjected to political restraint, scientists of all nations have always co-operated in solving Nature's jig-saws, and as Professor A. V. Hill said at Belfast,[3] 'The fundamental principle of scientific work is the unbending integrity of thought, following the evidence of fact wherever it may lead within the limits of experimental error and honest mistake.' This attitude of mind is not peculiar

[1] Address delivered on September 2, 1959, at the York Meeting of the British Association.
[2] See P. M. S. Blackett (1959), *Advanc. Sci., Lond.* **15**, *367*.
[3] Presidential Address (1952).

to scientists; it is common to all who have a respect for the truth. But in the fields of law, language, history, literature and, above all, politics, our general outlook and our individual range of knowledge depend to a very dangerous extent on local environment and national tradition. By freedom from such limitations Science provides ground—perhaps the most solid ground—for wider co-operation. But the gap between a scientific and a humanitarian outlook cannot be bridged by the statistical laws of physics and chemistry; we are forced to apply less precise, but not necessarily less important, principles from the world of living organisms. The challenge is, therefore, to the biological sciences, especially those which deal, at the borderline of sociology, with the behaviour of organisms and their relationship to their environment. The extent to which they can yield broad principles applicable to Man may well decide how far Science can claim to be of direct cultural significance.

II

Man's position in the world of Nature is brought most sharply into focus by the concept of natural evolution. Cosmic, biological and human evolution can be regarded as phases in a continuous natural process—and, from this point of view, astronomy, geology, biology, archaeology *and* history form a continuous spectrum of knowledge. To pass through many millions of years from a primaeval nebula to a modern man without any sudden break in continuity of thought gives a feeling of intellectual tidiness, but quite apart from this it enables us to visualise Man against the background of his past and to regard him as Nature's supreme masterpiece. At the same time, he must not get *too* big for his biological boots or tend to exaggerate the gap between himself and the rest of the animal kingdom. No animal can manufacture aeroplanes, or Asdic; but the prize for aeronautics must go to the shearwater which navigated the Atlantic without compass or chart, that for Asdic to the ears and vocal cords of our nearer relatives the bats. By surrounding themselves with an electric field, some fish (e.g. *Gymnarchus*) can, in total darkness, detect foreign objects in the surrounding water with very remarkable precision. The total weight of the mechanism involved—including the animal's brain—amounts only to a few grams; a man-made instrument of comparable performance would involve at least a ton of highly complex electronic machinery. Again, there is no laboratory in the world which can compete with the biochemical skill of even the smallest living organism. In fact, as delicate and precise pieces of machinery, Man's inventions so far compare very unfavourably with those which have come into existence during the natural course of biological evolution. On the other hand, we may fairly claim that we have accomplished in a few centuries things for which Nature required many millions of years. Nevertheless, we need not be in the least ashamed of the older members of our evolutionary family; we have still a great deal to learn from them.

To visualise Man's position in the animal world, it may be useful to define his main diagnostic characters. He is a highly gregarious bipedal mammal with unspecialised limbs but a *very* large brain. He is the only animal which has developed the symbolisms of speech and writing, and he may well be the only animal capable of rational thought. He is, therefore, the only organism which can hand on patterns of acquired learning from one generation to another. To these advantages he owes his dominant position in the world today. They have enabled him to exploit his environment and increase his numbers and his range of distribution far more quickly and far more extensively than any animal of comparable size. He has eliminated some of his competitors and exploited others for his own use, but the time has now come when different races of men are competing with each other within the closed arena of a limited environment, and it is not easy to see where

it will end. There is nothing equivalent to this in the inanimate world; but, when a biologist looks at the general trend of events, he is inclined to say, 'Where have I seen something like this before, what is it due to, and how does it *usually* end?'

One of the first attempts to subject social problems to biological analysis was made by Malthus in 1789 when he forecast the fate of a nation whose rate of increase was greater than that of the resources of its environment. Malthus did *not* say that war, pestilence and famine were inevitable; he said that they *were* inevitable unless people, by voluntary control, reduced their rate of reproduction. The theory of animal evolution by Natural Selection, enunciated just a hundred years ago by Darwin and Wallace, involves the principle of overpopulation and introduces the concept of randomly produced mutations. Some of these increase an individual's chance of survival; others decrease it. Those which best adapt the animal to the conditions of life imposed by the environment survive, the rest are eliminated; in other words, the course of *animal* evolution is not directed by the organism itself, but by the external environment. The individual animal throws the dice, but the environment decides the winning numbers. There is no evidence that adaptations acquired during the lifetime of an animal can be handed on to its offspring; each generation has to take an environment more or less as it finds it and make its own way in the world. A persistent struggle within an overpopulated environment is an essential condition for evolution by means of natural selection; it is the price which Nature demands for progress. There is also the danger of over-specialisation; a species whose structure has become very highly adapted to a particular environment may be extremely vulnerable if the environment changes relatively suddenly. The course of human evolution is entirely different. Speech and writing enable each generation to modify, extend and control its environment in the light of experience gained by its predecessors and to hand on acquired benefits without bodily specialisation. He is the master and not the slave of his environment, and as soon as he learns to discipline himself to the fact that his environment has become world-wide he can begin to direct the course of his own evolution without the discomforts of overpopulation. If he fails to realise his powers and allows things to drift, his future seems dark; if he really bestirs himself, there is no real need to be afraid.

Quite apart from any evolutionary significance, there can be no doubt about the validity of Malthus's argument. Western Europe and America have followed his advice; but, as stressed by Professor Blackett,[1] the density of population in other parts of the world is far higher than can be adequately sustained by the environment. We can, of course, shrug our biological shoulders and say that different races of men live in different environments and are, therefore, subjected to different intensities of struggle, and it would be nice if we could be quite certain that it is always the fittest which survive. We cannot salve our consciences quite so easily nor will *we* escape for very long from further environmental pressure. Our own population may remain relatively stable but our environment expands with almost every new major scientific discovery, and the greater the overlap of the environments of different nations, the fiercer is the competition. The situation is substantially the same as that of an expanding animal population within a limited environment. These problems lie within the field of Section F (Economics) but they are fundamentally similar to those which arise in animal ecology; it seems just as unrealistic to regard one race of man as an isolated unit as to study the population of one member of a biological food-chain without reference to those of all the others. The writing on the wall is tolerably clear; if Man behaves like an animal and allows his population to increase whilst each nation steadily increases the complexity and range of its environment, Nature must take her course and the Law of the Jungle prevail.

[1] Presidential Address (Dublin, 1957).

To see this law in action, it is useful to remember that Nature has made, not one, but two *great* experiments in the design of social animals. The first was carried out in Mesozoic times when Man's mammalian ancestors were beginning to emerge from reptiles. The results of this experiment are represented today by the social insects—notably the ants. There are a very large number of different species of ants, none of which interbreed; among them is found a range of complexity of social behaviour which is not only unique in the animal kingdom but which forms a very remarkable parallel to different races of human beings. At one extreme are species forming small communities, restricted to localised or specialised environments and exhibiting relatively little subdivision of labour between individuals. At the other extreme are large and often aggressive communities with marked differentiation of structure between different grades of individuals; populations of this type display high levels of co-operative effort involving, in some cases, the rudiments of agriculture and husbandry. In all cases, however, ant societies are organised on a straightforward totalitarian basis, the contribution made by each individual towards the welfare of the community is determined from the time of birth; each grade of individual is structurally adapted for predetermined tasks. How far ants can communicate with each other may be doubtful, but it is tolerably certain that members of the same community recognise each other by a characteristic smell, and as the brain of an ant is about the size of the head of a pin, it is perhaps not surprising that ants should attack or kill an individual from another colony with a smell slightly different to their own. It is much less easy to understand why a man, with a brain of an entirely different order of complexity, should, at times, react almost equally violently to skin pigments different to his own.

But it is not only in respect to individual relationships that the study of ants is relevant to Man. Ants are the only organisms which—apart from Man—indulge in organised warfare—raiding the nests of other species and incorporating captives into their own societies. But perhaps the most striking facts relate to species which have changed their habits and distribution within recent times. Two instances of territorial expansion are known to have occurred in the last 150 years.[1] Early in the nineteenth century an Eastern species (*Pheidole megacephala*), having spread rapidly over North Africa and South Europe, managed to reach the islands of Madeira and Bermuda; in both places it exterminated the smaller native races. Meanwhile, a similar policy had been carried out by another species (*Iridomyrmex humilis*), from the Argentine, which, having landed at New Orleans, very rapidly overran the southern United States; in due course, it too reached Bermuda, where it proceeded to eliminate the earlier invader. In the world of ants there is no place for small peaceful communities unless they can isolate themselves effectively from larger and more powerful neighbours, nor does there seem any lasting peace between large aggressive communities. Solomon's advice has, I suspect, been misinterpreted. It should read: 'Consider the ants, and, if you use your intelligence, you will see how *not* to deal with international problems.'

Having designed the ants, Nature waited for about 150 million years before embarking on her second or human experiment. She waited, in fact, until it could be carried out with a species in which an individual's contribution to society was no longer based on inherited structural characters but on the power of intercommunication with other individuals; in other words, until Man's brain had reached a level of development which enabled him to control his environment, and to deal rationally with the subdivision of labour between individuals and with the distribution of natural resources between different groups of individuals. At the same time she arranged that such groups should not be physiologically isolated from each other. Different races of men can interbreed, or they can, if

[1] Haskins, C. P. (1945), *Of Ants and Man.*

they wish, come to mutual agreement about the distribution of world resources. The first policy would seem to lead to a world state with uniformity of social pattern and of material interests; the second involves territorial limitations and economic agreements. Both, as we know only too well, involve great practical difficulties. All the same, men ought to be able to do something better than ants.

The second basis of comparison between Man and animals concerns the factors which control his behaviour. The past fifty years have produced a very great increase in our knowledge of animal behaviour. For present purposes, however, attention may be focused on two problems: the extent to which animals can profit from extraneous instruction, and the extent to which they are able to learn for themselves. The first of these fields is explored by means of the conditioned-reflex technique, whereby an animal learns to associate a specific visual, or other sensory, stimulus with forthcoming food or impending danger. In order to establish this result it is necessary to conform with five basic principles all of which have their counterpart in the training of human beings.

(i) The response expected from the animal must not be unduly complex; the animal must be able to reach the food or escape the danger by making reasonably simple movements. In other words, the problem must not be too difficult.

(ii) The lesson must be presented to the animal under conditions which ensure freedom from extraneous disturbance. It will not learn if its attention is constantly diverted by other changes in its environment.

(iii) The problem must be presented to the animal on an adequate number of occasions; the more frequent the lesson, the fewer the mistakes become.

(iv) There must be an 'incentive' to learn—a reward for success or a punishment for failure. Further, the 'reward' must be related to the needs of the animal.

(v) Finally, the experimenter must possess adequate skill and patience. The ability of an animal to learn depends to a very large extent on the personality and enthusiasm of the teacher.

These five principles apply equally well to the education of human beings if we make suitable allowances for increase in complexity of the lesson and for changes in the nature of the incentive to learn. But we can go a little further, for, as with men, different individuals of the same animal species learn at very different rates. Curiously enough, however, there does not seem to be any clear correlation between an animal's ability to learn and its position on the evolutionary tree. It is possible to trace the structural evolution of the human brain through each of the main classes of vertebrate animals; the large paired hemispheres of our brain arose in the Devonian lung-fishes and the cerebral cortex in the early Permian reptiles. It would be very convenient if step by step with an increase in size and complexity of the brain it were possible to trace a corresponding increase in complexity of behaviour and in ability to learn. This is not the case; some fish without hemispheres or cortex can exhibit behaviour patterns which seem just as complex as those of reptiles or even of some mammals. In due course this difficulty will be resolved, but for the time being one can only say that there seems to be one feature common to all species which learn easily, namely, a vivacious but not unduly excitable temperament—fish, rats, monkeys and children all have a natural tendency to explore their environment and they are interested in anything new or strange; they are all, perhaps, potentially good scientific observers.

But the value of the instruction given to human beings by a teacher is largely judged by the extent to which it enables a pupil to make use of his acquired knowledge and to go on to learn more by himself. Within the animal world there is very

little evidence to suggest that experience acquired from one pattern of environment or from one problem can be readily applied to others of a somewhat different nature. An animal's own approach to a problem, like that of a very young child, is very largely one of random exploration; once it has found the solution by chance, the number of ineffective responses on future occasions becomes less and less until the correct response is stabilised.

How far animals display evidence of the higher levels of mental analysis associated with "intelligence" in human beings is not too clear, for it is extremely difficult to subject intelligence to an agreed standard of measurement. When judged by human standards the I.Q.s of all animals are, undoubtedly, very low; but, it may be that we are not always setting *them* quite the right type of examination.

Although it is difficult to correlate an increasing capacity to learn with an increase in size and complexity of the brain throughout the main classes of vertebrates, it seems clear that there is a substantial increase in learning ability as soon as an animal's brain reaches a level of structural complexity comparable with that of man. The young chimpanzee, like a human baby, is typically a friendly playful creature dependent on and with an affection for its mother. But as it grows up, it begins to show marked signs of individuality; some become morose, unfriendly and vicious, others retain a friendly disposition towards their neighbours and a co-operative attitude towards human teachers. The ability to respond to training shown by the latter type of individual is, of course, very remarkable, but when left to itself a chimpanzee seems to rely on an initial process of trial and error. Like many other mammals, it can give audible and visible signs of fear, anger or pain; but there is no evidence that a chimpanzee can make audible or visible signs which other individuals associate with specific material objects; the mental development of the adult ape seems roughly equivalent to that of a human baby before the latter has learnt to speak. In short, nothing can possibly disguise the enormous difference between an adult ape and an adult man in ability to learn and to control their environments, but it might be argued that a relative test of the brains of the ape and of Man as computing instruments should be conducted on the basis that neither pupil nor teacher should be allowed to speak, read or write; the gap between animals and men might narrow very appreciably.

The third and perhaps most important biological aspect of Man's behaviour concerns the gregarious habit. Here again the distribution among vertebrate animals is curiously unrelated to their evolutionary history; it is well marked in certain species of fish, birds and mammals but absent in others. In some cases the existence of a herd or flock is clearly of survival value; a pack of wolves has a wider choice of food than an individual operating by itself. But it is not always clear why one species should be more gregarious than another to which it is closely related. In the present state of knowledge it may be safer to say that some animals are restless or uneasy unless in close proximity to individuals of the same species—that they have, in fact, a deep-rooted antipathy to isolation or loneliness. In any event the resultant grouping establishes the herd as a unit which responds as a whole to an external stimulus applied to one or a few individuals. The response is most clearly marked when the stimulus evokes an emotional reaction of fear or anger in the individuals directly concerned, and one of the most distinctive features of herd behaviour is the speed at which these emotions spread throughout the community. If certain individuals are more highly susceptible than others to external stimuli the response of the group is determined by the most timorous or the most belligerent members of the community. The majority of the herd subjugate their own individual behaviour to that of a few, and in the long run the individual benefits by greater security from predators or greater certainty of obtaining food. If an individual is unduly insensitive to emotional stimulation by its neighbours, it is likely to be eliminated by natural selection—the sheep that walks by itself gets

eaten and the solitary wolf may starve. These principles were applied to the analysis of human behaviour by Wilfred Trotter.[1] In order to avoid physical or mental isolation men are prepared to subjugate their own immediate needs or predilections to those of society as a whole. Antisocial activity is kept in check by fear of intellectual or physical isolation; feelings of increased security and greater freedom from personal doubts and fears are set off against loss of individual freedom of action. How far psychologists have developed or rejected Trotter's suggestions I do not know, but there can be little doubt that they opened up a useful biological approach to sociology by suggesting that our instinctive reaction to something new or strange is, as in animals, to conform with our neighbours, and that, at moments of crisis, it is better to follow a leader than rely on personal judgments. These and allied problems belong to Section J (Psychology). All I wish to stress is that the phenomena of mass psychology in Man, like other aspects of his behaviour, have their roots far down in his evolutionary history.

Perhaps the most striking difference between the social habits of Man and those of animals is the existence of a hierarchy or grading within human society. Only in a very few cases does this appear to exist within the animal kingdom. The nearest approach seems to occur in birds; a flock of jackdaws feeding in a restricted area resolves itself into a well-marked order of feeding priority. Conrad Lorentz has recently reported that if a high-ranking male decides to mate with a low-ranking female, the latter rises in social status and feeds with her husband; all this sounds reasonably familiar to human ears.

This is perhaps as far as a zoologist ought to go in trying to view mankind through biological spectacles. But one does not need to be a professional biologist to appreciate that the rates of change in the pattern of human behaviour and in the nature of our environment have, during the past five thousand years, been incomparably greater than those of any other organism at any period of its history; our clothes, houses, habits and social organisation change with successive generations. In fact, if one were forced to select the organism which best displays the phenomenon of persistent evolutionary change one would undoubtedly choose Man. I have tried to show that the broad principles which relate the size of human populations to the resources of their environments and those which govern an individual's ability to profit from instruction are qualitatively similar to those which apply to animals. On the other hand, Man is, as I have said, unique in that he can speak and write, and the later phases of his evolution can therefore be described in terms of social and economic history.

In suggesting further points at which biological principles seem to be applicable to the evolution of human society, a zoologist can only look towards Archaeology and Anthropology (Section H) and hope that his spectacles are not completely out of focus. In its very early stages human society must have been organised into quite small units each dependent on the natural resources of a small circumscribed environment. The discovery of fire and development of agriculture must have increased the range of the environment and the optimum size of the population required for its exploitation, and the stability of the group would become more and more dependent on the maintenance of an effective subdivision of labour; but the larger the population and the greater the degree of specialisation, the greater the limitations imposed on individual freedom of action. A new and very important social factor seems to have come into action when natural phenomena became linked with supernatural concepts—fear of isolation or reprisals from fellow-men being reinforced by fear of a superhuman agency and a sense of greater security inspired by reliance on supernatural support. Such beliefs had no material basis but they would be the cement which held society together and, as such, be of immense survival value. But it is difficult to avoid the conclusion that such beliefs,

[1] *The Herd Instinct in Peace and War.*

like scientific theories, must undergo change as Man's knowledge increases and his environment alters; from this point of view, it is not easy to regard any one belief as an expression of absolute and unchanging truth. It may be argued that such things lie outside the orbit of the British Association, but if Science is to be of direct cultural significance it cannot shut itself off from one of the main factors which have influenced men's attitude to social problems. A recent issue of *Nature* contained a leading article on the proceedings of the last Lambeth Conference, and it must have been a very long time since an Archbishop of York addressed such a conference in language which scientists could so readily understand. Against such a background, the sciences and the humanities surely ought to be able to find something in common.

III

It is easy to say that Science should be welded to the humanities, but much less easy to suggest how this should be done. Each of us has a different view according to our particular interests. I confess that my own approach is based on personal experience. About fifty years ago I chose to specialise in biology, and from time to time I have been asked 'If you had known that you would spend a good deal of your later life studying the movements of animals, what subjects apart from biology would you have read at school and at the university?' The answer is simple: Apart from modern languages, I would have read physics, chemistry, mathematics and mechanical engineering. The moral is that no young scientist should be allowed to forget that new discoveries tend to arise from the borderland between different subjects where the discipline of one is applied to another. Had I appreciated this I would have been a much better biologist, but whether I would have been a better human being is another matter. If I am asked the sixty-four thousand dollar question, 'Had you known that you would have had to adjust yourself to a rapidly changing and somewhat uneasy world, what *additional* training would you like to have had?', I think my answer would be that I would like to have been trained to think dispassionately about social and political affairs in the light of experience drawn from the past, and to have been taught to appreciate beautiful things. But could I have acquired this knowledge whilst training as a scientist? Perhaps not, but I still think that I could have been shown a wider picture. Having been taught to visualise the spectrum in terms of the wavelengths of light, could not I have been encouraged to learn a little about colour as a source of aesthetic pleasure? Why learn about the properties of iron and carbon without reference to the Industrial Revolution? I might even have developed a taste for the classics if I had known that Aristotle had written a very good text-book of zoology. Perhaps I expected too much in hoping to appreciate an artist's view of Nature from the standpoint of a scientist. But I am not completely convinced. A scientist's attitude towards his observations does not seem to me to be so very different from that of a poet towards his words or a painter towards his colours; isolated observations have no more value than single words; it is only when they fit into a satisfying pattern that the scientist feels he has achieved his end. If this argument is unconvincing, and if it still seems impossible to combine the vision of the artist with the outlook of a scientist, I can only suggest that Leonardo da Vinci and Sir Christopher Wren seem to have had pretty good *shots* at it. It would be very interesting to know the sort of training *they* had in early life.

But a plea for a wider outlook in the teaching of Science is nothing new. It was urged again and again by Sir Richard Gregory. In 1933 the declared aim of the London County Council was that they 'wished their pupils to obtain a broad view of nature, to study mankind and his environment from various standpoints, more particularly from the point of view of both the biological and physical Sciences'. In 1946 the Advisory Council for Secondary Education in Scotland was even more

explicit: 'The study of man in his world, like the study of science, is a unity which should not be broken by any sharp division into 'subjects' . . . the theme must be one.' Only last year (1958) a committee of the Science Masters Association urged that 'The schools have the duty of presenting Science as part of our common cultural and humanistic heritage; it should be taught in harmony with and not in opposition to the various Arts subjects. . . .' It seems fair to say that this is a goal towards which we would all wish to strive; but when we try to approach it the road proves extremely hard, and most of us, in practice, fall by the wayside.

We cannot shut our eyes to the fact that our national economy depends on our ability to make and exploit new scientific discoveries. If we wish to maintain or extend our standards of material comfort we must have more professional scientists and highly trained technicians and we must be prepared to devote an adequate fraction of our educational effort to get them. But highly trained specialists form only a very small proportion of the population, and we may be paying for them in very hard currency if we have to deny to a very much larger fraction of the community a reasonable chance of 'seeing life steadily and as a whole'. A democracy has to decide how much of its total educational effort should be devoted to an ever-increasing standard of living and how much to raising the intellectual standards whereby the majority of the population forms its judgments on things which involve personal prejudice or political propaganda. It is not easy to assess the factors which mould public opinion, but a recent enquiry indicates relatively clearly that the attitude of mind of an individual towards a changing environment is directly related to the nature and extent of his full-time education and that it is this training which largely determines, in later life, his response to other potential sources of education—such as libraries and broadcasts. If we wish to awaken a widespread interest in Science, or still more, wish to contribute toward the formation of an enlightened public opinion, we must sow our seeds in the schools and in organised centres of adult education.

But the key to the main problem lies in the schools, and the responsibility resting on school-teachers can hardly be exaggerated. Too many are asked to do two jobs at once—to provide a training for potential specialists and at the same time give a training which will best equip the average boy or girl for later life.[1] If we are to pay more than lip-service to the belief that a good all-round education is the best means of raising the intellectual level of the community, we must recognise that our most urgent need is for good general practitioners in the art of education. Really inspired teachers working with adequate but simple equipment will achieve more for general education than specialists in highly equipped laboratories. But the scales have been heavily weighted in favour of specialisation. Almost exclusively, our universities are producing specialists. Some of these return to the schools where they in turn teach on a specialised front. So the spiral of specialisation has gone on. It is only natural that able teachers get an intellectual stimulus by preparing boys and girls for scholarship examinations and so providing recruits for fields of research in which they themselves are interested; but it is by no means clear that their work is necessarily more important, or more difficult, than that of those whose primary object is to persuade people that they cannot live by bread alone. If we really believe in general education, we must produce and encourage the right type of teacher. No man or woman in their senses enters the teaching profession for financial gain, but a community which rates thirty inspired school-teachers as equivalent to one high-grade clown or film star may well deserve a very unhappy fate. A benevolent dictator would make school-teaching the most highly respected and the most highly paid of all professions and the Ministers of Education the most important and most highly paid officers of

[1] *Proc. Brit. Assoc. Conference*, 'Science in Schools' (1958).

government; but, in both cases, he would demand a very, very high level of performance. But we had better do the best we can without him.

The value of an educational system can perhaps be judged by the extent to which it leaves people with a desire to know more about the world at large and a feeling that this can be satisfied, at least in part, by personal effort. To meet a constantly changing environment the general pattern of teaching must be constantly under review. If a curriculum is allowed to degenerate into a series of isolated subjects with little or no obvious bearing on each other or on everyday life, dry rot inevitably sets in; the result can, perhaps, best be described in words which I think the President of Section L (Education) will recognise: 'When far too many boys and girls will carry away from school little more than gobbets of ill-digested knowledge and a distaste for what has yielded *so* little.' [1]

But, as I have said, it is easy to talk and to criticise; it is much harder to plan for action. As far as science is concerned, we might approach the problem of general education in the three familiar stages of research, development, and production. The first step would involve an assessment of the evidence; if the Association's judgment were given in favour of a wider and more social outlook, it should do all it can to see that it is put into practice on a limited front and—in the light of experience—allowed to spread gradually into full-scale production. All this would involve very far-reaching reorganisation of schools and universities. But while Oxford and Cambridge shiver on the brink of optional Latin, the University College of North Staffordshire is swimming the Hellespont. All its students, during their first year, jointly survey the whole field of knowledge as a coherent picture before proceeding in three subsequent years to specialised training. This is, in my opinion, one of the most important and courageous educational experiments in our times, for, if it succeeds, a great number of our major difficulties will be resolved.

On the other hand, if 'general education' and 'general science' are condemned as 'smatterings of everything and a knowledge of nothing', and if the concept of a central theme round which all parts of a syllabus would revolve be found to be illusory, it is high time we stopped talking about the broad cultural value of science and concentrated our efforts on widening the interests of specialists during or after their technical training. Much can be done by relatively formal teaching, but—if I may judge from personal experience—more depends on the extent to which people are given the time and opportunity to educate themselves by contact with men and women of entirely different interests and outlook from themselves. This is the great strength of the older residential universities; but, here again, it is just conceivable that they may have something to learn from North Stafford.

But the older we get, the less inclined we are to go back to school. If we want every member of the population to keep in touch with what is going on in the scientific world and to realise its impact on their lives, we must rely on the Press and on the broadcasting authorities. In respect to music, the B.B.C has been outstandingly successful; other fields of broadcasting may be less amenable, and it is not altogether easy to know how far an increase in factual knowledge concerning a number of isolated fields of science enables listeners to appreciate the broad social and international implications of science as a whole.

But when all is said and done, Science can only make its full contribution to the welfare of mankind if it is used as a means of encouraging a dispassionate but optimistic attitude towards all aspects of human affairs. To move from national traditions and aspirations to others based on international welfare may prove less painful if we are prepared to look on Man and all his problems as a phase in the evolution of the universe and if we have the courage to believe and to teach that he can, by means of his intellect, control and direct his own evolution and destiny.

[1] *Report of the Advisory Council on Education for Scotland* (1946), p. 25.

THE VISUALISATION OF MAGNETIC PROCESSES[1]

ADDRESS BY PROFESSOR L. F. BATES, F.R.S.

PRESIDENT OF SECTION A

ON THE LAST OCCASION when the British Association met in York, Sir Alfred Ewing was President of the Association. I mention this fact because Ewing was so much concerned with the early development of modern magnetism, and I recollected that only some two years previously, at a Symposium on Magnetism arranged by the Physical Society in London, some of us had heard him state that he thought 'no small beer' of himself when he produced a hysteresis loop for the first time. In view of the encouragement we are now giving to young people to join the British Association, it is interesting to remember that Ewing attended his first B.A. meeting when he was only twelve years old.

In a way, the 1932 Meeting is a landmark in the history of magnetism, for there had just been found a means of making visible many magnetic processes which were suspected to take place as a result of recent studies of the magnetic properties of single crystals of iron. I refer to Bitter's discovery that very finely divided magnetic particles formed definite patterns when they were allowed to settle upon suitably prepared surfaces of ferromagnetic metals. Indeed, I was tempted to give my address the somewhat popular title 'Beyond Iron Filings', because Bitter's work really amounted to plotting lines of magnetic force or making visible surface magnetism, with microparticles in place of the coarse iron filings which we used in our younger days, and which our descendants will probably continue to use for many years to come.

Now, just as the knowledge that one end of a bar magnet is north-seeking, is of service to the young person about to map lines of force around it by the iron filings method, so some idea of the possible magnetic structure of a ferromagnetic body, and in particular, of a single crystal of a ferromagnetic metal, is of great help to more senior workers. This is provided by the domain concept, a concept which is now over fifty years old. We picture a ferromagnetic body, in its simplest form, as made up of a very large number of domains, or small regions, each magnetised to saturation along one of a limited number of directions which we term easy directions of magnetisation. In the case of an iron crystal there are six such directions, respectively parallel to the edges of the crystal cube; in the case of cobalt there are only two, parallel to the hexagonal axis of the crystal.

Perhaps the best way of explaining the concept is to describe the domain structure of an unmagnetised strip of cobalt cut from the side of the hexagonal crystal. The domains are magnetised up or down, in the manner shown in Plate I (*a*), the volumes of material magnetised in the two directions being approximately equal. If, now, we could paint black the surface of those domains which are magnetised upwards, we should obtain a picture like Plate I (*b*). Alternatively, if we could blacken only the boundaries between adjacent domains, we should get a picture like Plate I (*c*). But, both Plates I (*b*) and I (*c*) are actual photographs of the surface of a cobalt crystal, obtained by modifications of the Bitter technique which will be described later. Incidentally, it is very easy to magnetise the cobalt strip parallel to the hexagonal axis, when the domain boundaries move sideways, or disappear,

[1] Address delivered to Section A (Mathematics and Physics) on September 3, 1959, at the York Meeting of the British Association.

thus causing one set of domains to grow rapidly at the expense of their neighbours, but it is extremely difficult to magnetise the strip perpendicular to the hexagonal axis. This is one of the most striking examples of what is termed ferromagnetic anisotropy, a feature of ferromagnetism to which we must often refer.

If we cut a narrow strip from the cube face of a crystal of iron, so that its long axis is parallel to a cube edge, in the unmagnetised condition we might find a principal domain structure similar to that of Plate I (*c*). In addition, because there are two further directions of easy magnetisation in the surface, we should certainly expect to find some small triangular, wedge-shaped domain structures at each end of the strip as are shown in Plate I (*d*). These are called closure domains and their function is to ensure that lines of magnetic force do not leave the ends of the strip.

We think, therefore, that our simplest ferromagnetic specimens consist of blocks of magnetised material separated by boundaries. The blocks on the two sides of a boundary are usually magnetised either antiparallel to one another, or perpendicular to one another, and, accordingly, we distinguish between 180° walls and 90° walls or boundaries. We see that these arrangements ensure that there are no 'free poles' or surface distributions of magnetism over a domain wall. Indeed, with the perfect arrangements of domains shown in the various diagrams which we envisage, there should be very little free magnetism anywhere. However, if the actual crystal surfaces are not cut strictly parallel to true atomic planes, but inclined if only at very small angles to them, we may get surface magnetism over the external surfaces of the specimens.

In any case, the domain walls must be regions of transition between neighbouring domains, and we must picture a gradual rotation of the direction of magnetisation in the material within a domain wall as we traverse it from one side to the other. The thicker the wall, the more gentle the transition of exchange energy, but the greater is the quantity of material magnetised in difficult or unfavourable directions. Hence, the final wall thickness is settled by a compromise between the competing claims of what is termed magnetic exchange and of magnetic anisotropy. Whenever a domain wall cuts a crystal surface there must be a surface distribution of magnetism over the edge of the wall, which means that a stray magnetic field must exist over that narrow region. If this stray field is sufficiently intense, we may use it to attract tiny magnetised particles in its neighbourhood and so make visible the existence of the wall (as in Plate I (*c*)). This is the basis of much of the experimental work now about to be described. We want to know as much as possible about the walls, their width, their modes of termination, their methods of formation and disappearance, how they move, what happens when they meet an obstacle or an imperfection in the crystal, and so on. We want to know as much as possible about principal and subsidiary domain structures and their bearing on those magnetic processes which determine the bulk properties which are so important to users of ferromagnetic materials.

At the outset we must distinguish between two main methods of attack upon the problems—static and dynamic. If any kind of particle or powder technique is used, it follows that the deposition of the particles will take time, and rapid changes in domain configuration cannot well be followed. Consequently, for the visual observation of rapid changes, a method based on the reflection or transmission of polarized light must be used. Such methods have recently been developed, and, with the discovery that thin crystals of garnets containing the rare earth metal yttrium are ferromagnetic and transmit visible light, they are likely to lead to spectacular results.

Let us now consider some of the more outstanding results of the powder technique. We must start with a strain-free and highly polished surface. This may be obtained, first by careful mechanical abrasion of the surface, which gives a high polish but, unfortunately, leaves it covered with an upper glass-like, amorphous,

and a lower heavily strained crystalline layer altogether some thirty microns thick, and so makes it unsuitable for the examination of domain structures. These layers must therefore be removed by electrolytic polishing. Optical and, if necessary, X-ray examination is made to learn how accurately the surface approximates to a required crystal plane. Assuming that it is satisfactory, the surface is mounted horizontally on the stage of a metallurgical microscope, and a drop of liquid containing finely divided colloidal magnetite, prepared according to recipes of Elmore and Bozorth, or the more recent one of Craik and Griffiths, is placed upon it. Very quickly the colloid collects above domain walls and a pattern may be viewed and photographed.

It is exceedingly difficult to cut a metal crystal so that its surfaces are true crystal planes. For example, if we take an unmagnetised strip cut from the cube face of a crystal of iron, or rather silicon-iron, which is so much easier to obtain, we do not in general get a simple pattern, but a 'fir-tree' pattern. The trunks of the fir-trees are usually 180° walls, and sometimes 90° walls, and they tell us the main features of the principal domain configuration in the strip. The branches represent a remarkable system of closure domain patterns, formed by the intersection with the surface of ellipsoidal-shaped domains emerging from the principal domain walls. A good example is shown in Plate II, where the pattern indicates to experienced workers that the surface makes an angle of about 1° with a true crystal cube face. If the surface were strained the patterns would be a complicated but very reproducible zig-zag or maze. The patterns on strain free surfaces in which we are generally interested are seldom, if ever, reproducible. A typical strain pattern is shown in Plate III.

The specimen may be placed in the field of a simple electromagnet and magnetised parallel or perpendicular to its surface, and we may then observe the motion of the walls which we hold responsible for changes in the bulk magnetisation of the specimen in weak fields. The sideways motion of 180° walls is beautifully shown in the case of cobalt, which is so simple from a magnetic viewpoint. Magnetoplumbite, PbO $(Fe_2O_3)_6$, which is formed as a waste product in the manufacture of ferromagnetic garnets, gives exceedingly fine domain boundaries. A few are shown in Plate IV (*a*), (*b*) and (*c*) which represent three stages in the increasing bulk magnetisation of a specimen in a direction parallel to the boundaries, the unmagnetised, partially magnetised and saturation states, respectively. They are much more convincingly shown in the film which I now project.

Let us now turn to the rather more complicated, although very important domain structure, of a strip of silicon-iron crystal cut with its upper and lower surfaces (100) planes (or cube faces) and its side surfaces (110) planes so that the long axis of the strip is a [110] direction or cube face diagonal. We frequently refer to such a strip as a Néel cut, as he first showed that in the demagnetised condition the domain structure would be that shown in Fig. 1 (*a*), where are depicted a number of principal domains, like the edges of the leaves of an album, each leaf magnetised in a regular manner parallel to one or other of two edges of the crystal cube, as indicated by the arrows. In addition to the principal domains, there are certain triangular, wedge-shaped closure domains, labelled q. When the strip is placed in a magnetic field and magnetised in the direction shown, Néel supposed the structure to change to that of Fig. 1 (*b*) with the appearance of new p closure domains.

We see, then, that on the upper surface of the specimen the domain walls should form a series of straight lines perpendicular to the long axis of the specimen along which the field is applied. Their distance apart should be a known function of the magnetic field and of the energy stored in each of the magnetised portions and in the domain walls. We have therefore studied the phenomena quantitatively by photographing the lines and comparing the average measured distances of separation with the theoretical distances for measured fields. Measurements of many

series of photographs such as those which I now show you (*vide* Plate V (*a*)), leave no doubt that the Néel domain structure is substantially correct. There is, however, some numerical discrepancy, for the measured distances are roughly twice as great as we would expect, even if we suppose that we are only able to photograph every alternate wall, since the applied magnetic field either assists the stray field above a wall to collect colloid or hinders it from doing so. But, the numerical discrepancy need not trouble us unduly, for when we photograph the powder patterns on the long side faces of the strip, we find them to be of much greater complexity than the

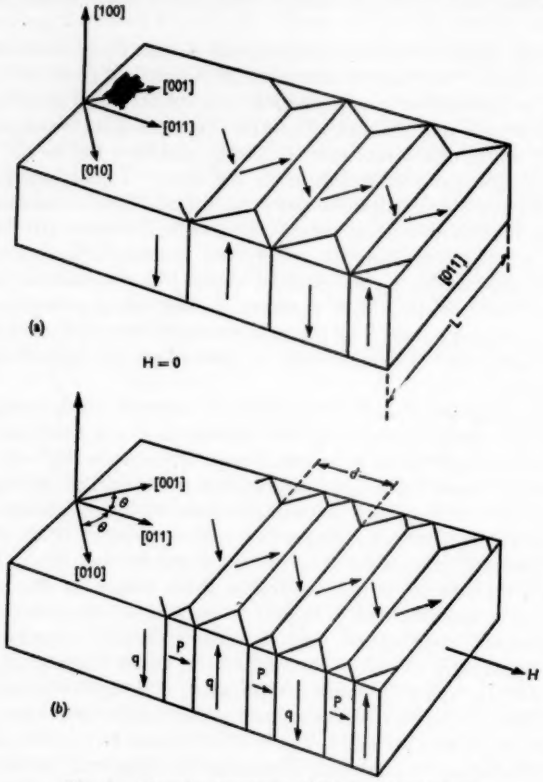


Fig. 1.—Domain structure of Néel-cut specimen.

Néel theory indicates, although the average separation of the domain walls measured on the top and on the side faces under stated magnetic conditions is the same. Some of the side patterns are very beautiful (*vide* Plate V (*b*)), and we call them lace patterns; it is thought that they are due to a system of closure domains of strange nature or, more likely, to the existence of surface magnetism.

We therefore realise that the magnetic behaviour, e.g. the hysteresis (*I*, *H*) curve of a strip specimen may be profoundly modified by the occurrence of unsuspected, subsidiary phenomena located at its sides. It is interesting to speculate what happens when a Néel cut specimen is placed in an increasing field. The original calculations showed that the lines should reach a minimum distance apart and then open out again. This is contrary to what is observed; the lines continue to approach closer and closer, but, unfortunately, become more and more indistinct, so that we cannot examine their high field behaviour by the powder pattern technique. This

is a great pity, for it would be so interesting to see exactly how the walls disappear as the strip forms one large, single domain.

I should now like to deal briefly with some refinements of the technique, recently made by Craik and Griffiths at Nottingham. Craik found that when a colloid to which has been added a little sodium carboxy methyl cellulose, a water soluble plastic, is allowed to dry on a smooth surface, the colloid particles eventually set in a dispersed state within a solid plastic film. On removal of the dry film, we have in it a permanent record of any domain pattern formed, and we may examine it with either an electron microscope or an optical microscope. The new technique is very important, because it may be used even when the specimen surfaces are non-planar, provided only that they are smooth. This has made possible the examination of domain structures on ferrites with surfaces obtained by simple cleavage. Results of an examination of a cleaved (100) surface of manganese ferrite are given in Plates VI (*a*) and VI (*b*). The former is an optical record, while the latter is an electron-micrograph of a portion of the former picture, and here the spacing of the deposits is 0·3 micron only.

Craik used the technique to measure directly the thickness of a domain wall by examining the deposits formed by a range of solutions of ever decreasing colloid content. He found that the finest continuous line deposit he could obtain on cobalt was 10^{-5} cm. wide, a result which is in good agreement with theory.

Craik's electronmicroscope technique is peculiarly suited to the examination of patterns on the basal plane of a cobalt-like crystal, where the characteristic star patterns represent the ends of closure domains, shaped as spikes, running into the bulk of the crystal, parallel to its axis. Plate VII (*a*) shows their great beauty. They appear to be formed in miniature whenever a scratch is found on the side of a cobalt crystal, as in Plate VII(*b*); exceptionally fine patterns are sometimes found on minute twin crystals, as shown in Plate VII (*c*). In the course of a study of basal plane patterns, with barium ferrite Craik obtained Plate VII (*d*), in which it seems that the 'fairy rings' may represent walls of a rare and special kind.

The usual powder technique enables us to see the importance of small inclusions, defects, impurities or tiny artificial deformations in magnetisation processes. For example, let us consider a small inclusion in the surface of an iron crystal. We cannot suppose that free poles may form on its sides, since the magnetostatic energy associated with them would be so large. Consequently, a system of closure domains around the inclusion is expected. Two cases are of particular interest. In the first, the inclusion lies wholly within a principal domain, and a closure domain takes the form of a pair of spikes running approximately at an angle of 45° with respect to the principal domain magnetisation, a feature first photographed by Williams (*cf.* Plate VIII (*a*)). In the second case (Plate VIII (*b*)), a 180° boundary passes directly through the inclusion, and two simple closure domains in the form of isosceles triangles are formed on opposite sides of the inclusion. Both cases have often been photographed, although the second one is much the more rare.

It is especially interesting to observe what happens when a boundary strikes an inclusion as it moves across a crystal surface on changing the magnetising field in which it is placed. D. H. Martin recorded an interesting series of pictures showing the formation and afterwards the destruction of a closure domain system as the wall passed by. The phenomena are so complex that they cannot possibly be reversible, and so we get an insight into an important way in which hysteresis losses may occur. We may perhaps think only of reversible processes when a simple wall does not rupture, and of the field which causes rupture as the measure of coercivity.

I now turn to a phenomenon whose importance has only recently been appreciated. In Plate VIII (*c*) two 180° boundaries are seen. To the left of the boundary, near the middle of the picture, is an inclusion on which is based a long spike closure domain running upwards to the left. Between the two walls a somewhat

deformed spike rises from another inclusion. But, in addition to the spikes, one observes that both inclusions are joined to the boundaries by tubes, which again we think play an important part in hysteresis losses. As a wall is made to move away from an inclusion by changing a magnetic field parallel to the wall, the tube appears to reach a critical length and then collapse to form a spike. And, when a wall is likewise caused to move towards a short spike, this elongates and attaches itself to the wall. We are now trying to investigate this tube extension phenomenon under controlled conditions. In the course of such a study Griffiths obtained an excellent set of photographs showing the approach of a wall to a small pit formed in a surface during polishing, its passage over the pit and its eventual rupture therefrom. The formation of the tubes, their collapse and almost complete disappearance when the wall intersects the pit, their re-formation and final rupture were beautifully recorded. Such processes cannot possibly be reversible, and they must be common inside polycrystalline materials where their formation and disappearance must be accompanied by micro-eddy currents.

Subsidiary domain structures are not always formed when a wall intersects an inclusion. The micrograph of Plate VIII (*d*) shows a wall on magnetoplumbite which has simply been much distorted by an inclusion which happens, in this case, to be just below the surface.

Incidentally, relatively few experiments have been made on polycrystalline materials, because a specimen must possess a grain structure sufficiently large to enable reasonably undisturbed domain patterns to be formed, and it is advisable that the individual grains under examination should have a definite crystal plane located in the surface of the specimen. Dijkstra and Martius examined the changes in the domain pattern of grain-oriented silicon-iron with large grains when the specimen was put under tension within the elastic range. Taking a crystal grain with a (110) plane in the surface of a specimen they applied a tension along the [110] direction, and found that under a stress of approximately 1 kgm. per mm.^{2} the original domain pattern vanished, and that after a transition stage with increasing load, a new stress induced pattern appeared. Frequently, one observes such patterns in strained portions of single crystal specimens (cf. Plate III). Patterns on polycrystalline alcomax have been studied, here and in America, in an attempt to explain the mode of action of a magnetic field when it is applied during the heat treatment of such materials to produce valuable permanent magnet properties.

The patterns found on suitable specimens often give clear indications of the orientations of the polycrystal grains. With adjacent grains of closely similar orientation, the patterns are often continuous from one grain to the other, while grains of differing orientations have distinctive patterns with a sharp line of demarcation at the grain boundary (cf. Plate IX). We were able to compare the spacings of a lace pattern on single crystal and polycrystalline specimens of approximately the same thickness and we found good agreement between the two. It is very strange that some of the lace patterns found on the grains of a polycrystalline specimen do not run parallel to the [100] direction but at an angle of over 10° thereto.

It is always a source of wonder to me that one can take a flat, thin ring specimen of (polycrystalline) perminvar, an alloy of approximate constitution nickel 45, iron 30, cobalt 25, and so magnetically anneal it by cooling it in a magnetic field, that a single domain wall runs completely round the middle of the ring and may be manifest by the powder technique. When we make such a wall move, we may obtain strange, re-entrant hysteresis loops. The motion of the wall may be followed by a polarized light technique or deduced from the pick-up in a search coil wound on a portion of the ring. Using extremely small rings and frames, P. F. Davis nucleated walls by a field pulse, and used the latter technique to follow the wall motion and to make a direct estimation of the energy per unit area of the wall. One of his

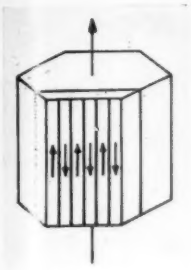


PLATE I*a*

PLATE I*b*

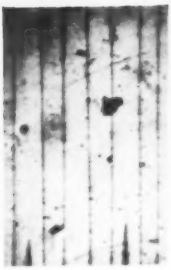


PLATE I*c*

PLATE I*d*

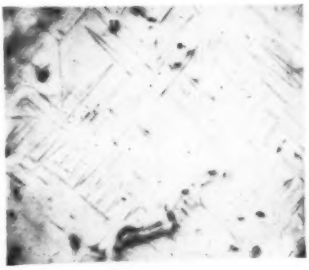


PLATE II

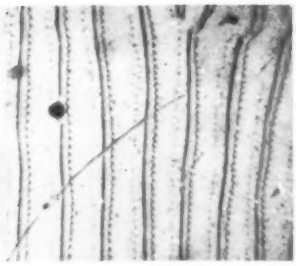


PLATE III

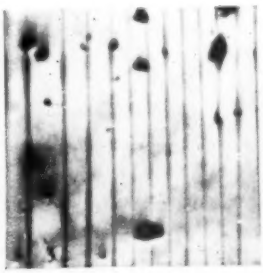


PLATE IV*a*

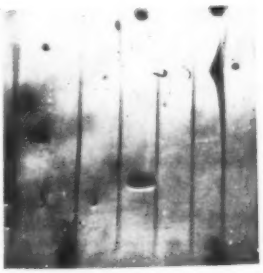


PLATE IV*b*

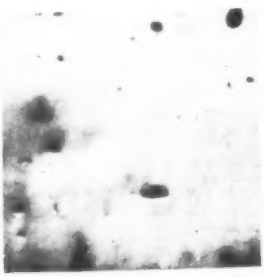


PLATE IV*c*

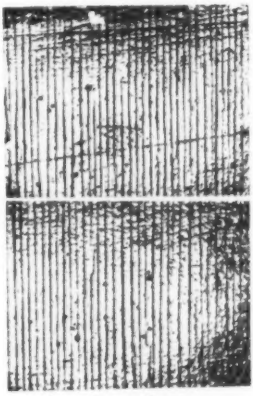


PLATE V*a*

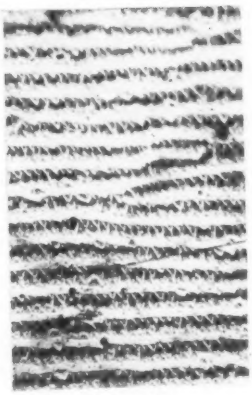


PLATE V*b*

Plate I*a*
I*b* (× 68)
I*c*
I*d* (× 38) — Illustrating domain structure of cobalt

Plate II (× 43) — Triangular closure on (100) surface of silicon-iron

Plate III — Domain pattern on approximate (100) surface of silicon-iron
Typical strain pattern on surface of silicon-iron

Plate IV*a*
IV*b*
IV*c* (× 85) — Illustrating domain wall spacing on uniaxial crystal surface

Plate V*a* (× 8) — Typical lines on (100) surface of Néel cut specimen

V*b* (× 63) — Typical lace pattern on (110) surface of Néel cut specimen

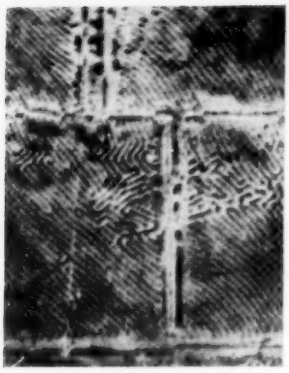


PLATE VI*a*

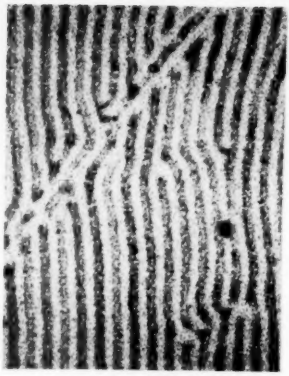


PLATE VI*b*

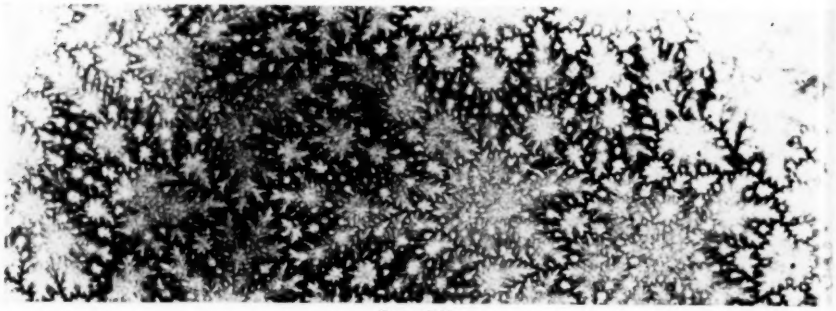


PLATE VII*a*

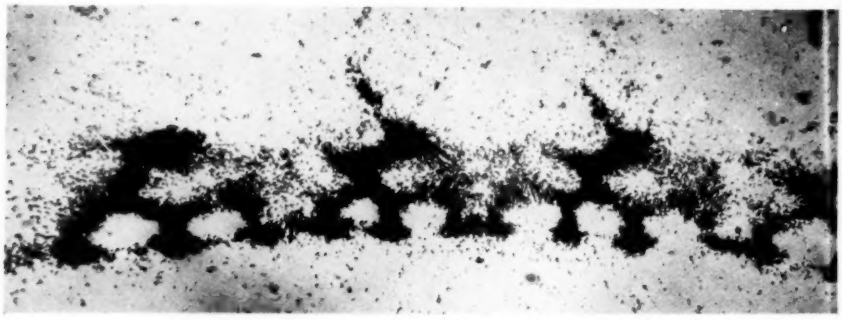


PLATE VII*b*

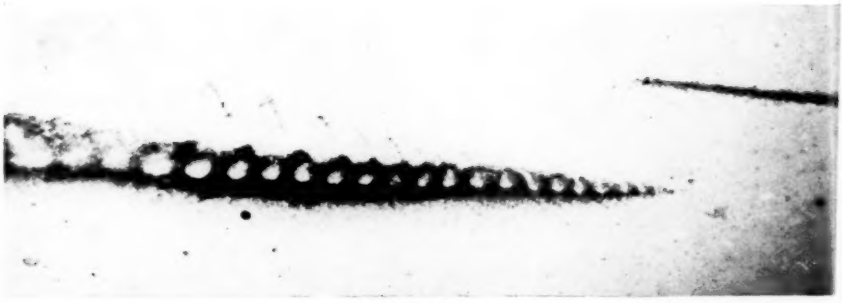


PLATE VII*c*

Plate VI*a* (× 540) Domain pattern on cleaved (100) surface of manganese ferrite

VI*b* (× 4,050) Electronmicrograph of portion of pattern in VI (*a*)

Plate VII*a* (× 1,620) Electronmicrograph of star pattern on basal plane of cobalt

VII*b* (× 4,860) Patterns in region of a scratch on axial plane of cobalt

VII*c* (× 5,940) Fine patterns near minute twin crystals

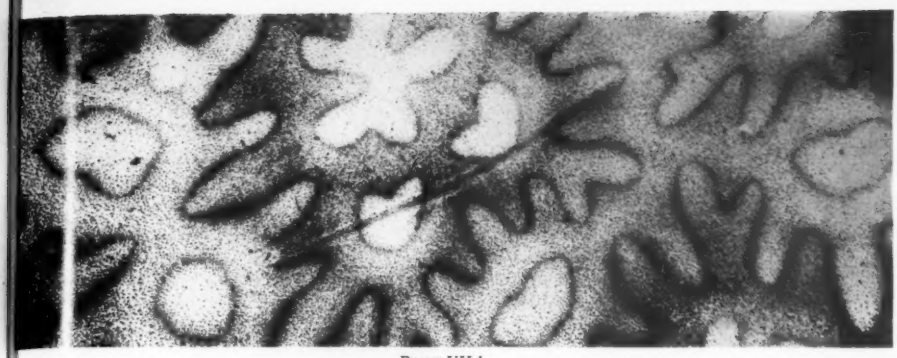


PLATE VII*d*

PLATE VIII*a*

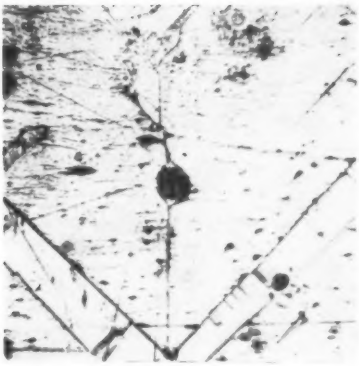


PLATE VIII*b*

PLATE VIII*c*

PLATE VIII*d*

Plate VII*d* (× 6,480) Ring patterns on basal plane of barium ferrite

VIII*a* Typical Néel spikes away from domain walls

VIII*b* (× 49) Effect of inclusion on domain wall

Plate VIII*c* (× 49) Formations of spikes and tubes

VIII*d* (× 1,620) Unusual wall distortion by inclusion on magnetoplumbite (Craik)

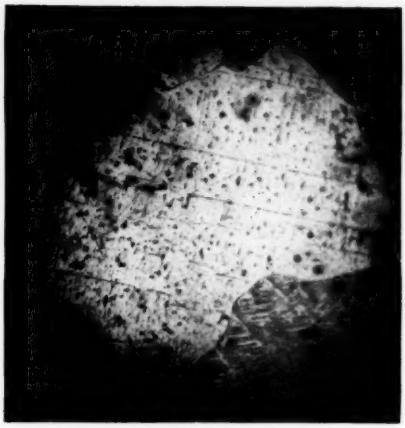


PLATE IX

PLATE X*a*

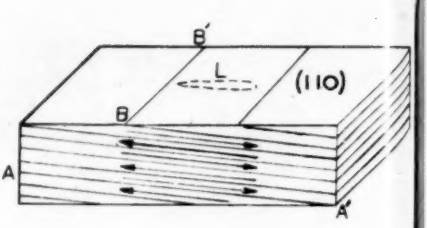


PLATE X*b*

PLATE XI*a*

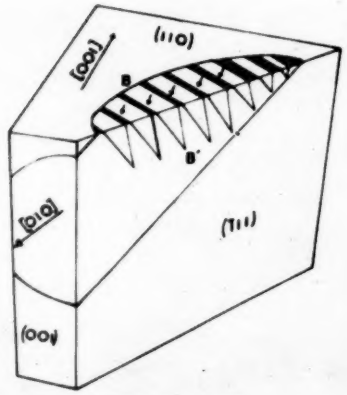


PLATE XI*b*

Plate IX — Domain patterns on surface of polycrystalline silicon-iron

Plate X*a* (× 68) — Lozenge patterns

X*b* — Diagram of formation of lozenge

Plate XI*a* (× 68) — 'Tadpole' patterns

XI*b* — Diagram of formation of 'tadpoles'

specimens was only 1·4 mm. in diameter. It was beautifully cut to an accurate geometrical form by a simple and relatively cheap spark cutting technique.

But the best way of following the motion of the wall is by a polarised light technique, perfected by Lee, Callaby and Lynch, which has the advantages that it may be used over a range of temperatures to study rapidly moving boundaries on ordinary, unpolished surfaces, without the restriction that the boundary must be narrow. The last advantage is important, for in materials of low magnetic anisotropy, the boundaries are obliged to be so wide that the stray field above them is unable to attract colloid.

Let us imagine that we have a thin, flat ring of magnetically annealed perminvar and that a single 180° wall runs round the middle of the ring, separating two oppositely magnetised domains. Theoretically, we might make use of three distinct modes of examination of the system by means of the magnetic Kerr effect using the polar, longitudinal and transverse effects, respectively, depending upon the disposition of the magnetisation vector in the reflecting surface with respect to the plane of incidence of the plane polarised light falling upon it. The three cases are shown in Fig. 2. We may consider that on reflection from a magnetised surface there is a small rotation of the plane of polarisation, to the right or left, depending

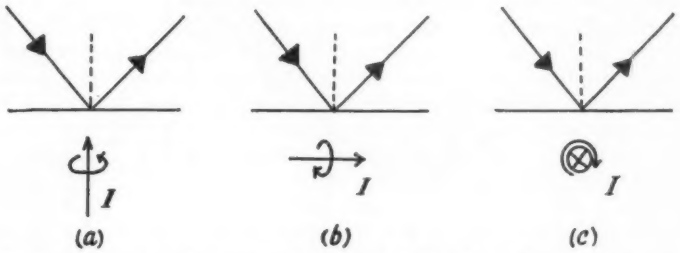


Fig. 2.—Diagram illustrating change in polarisation of light reflected from a magnetised surface, (*a*) polar effect, (*b*) longitudinal effect, (*c*) transverse effect.

upon the direction of magnetisation in cases (*a*) and (*b*). The polar effect (*a*) is somewhat larger than the longitudinal effect (*b*) and both have been used by Fowler and Freyer, with suitable optical arrangements, to pick out neighbouring domains as alternate bright and dark bands; but the method undoubtedly calls for considerable skill and special techniques to enable domain structures to be elucidated when surface imperfections are present. But the transverse effect, case (*c*), may be ascribed, not to a rotation of the plane of polarisation, but to a change in reflection coefficient with change in direction of magnetisation, and it is this effect which has been so successfully used by Lee, Callaby and Lynch.

Their apparatus is shown diagrammatically in Fig. 3. In effect it consists of two similar polarising microscope barrels, each mounted so that they may be rotated about a horizontal axis perpendicular to the plane of the screen. Arrangements are made for accurate alignment of the optical system and for variation of the angle of incidence. The specimen under examination is placed on a horizontal platform provided with the usual micrometer movements. A light probe is formed by focusing with the first microscope a narrow rectangle of light on the specimen surface. The reflected light is collected by the second microscope and falls upon the cathode of a photomultiplier, instead of an eyepiece. Single-layer polaroids are inserted as shown.

Let us consider the reflection of plane polarised light, when the polaroids are nearly crossed, from a small area of the specimen. If a domain wall moves across the area the intensity of the light falling on the photomultiplier will change, and the

change may be made periodic by the application of a small alternating magnetising field to the specimen. The current from the photomultiplier may then be amplified independently of the larger, steady current upon which it is superimposed. Consequently, a signal of the same frequency as the applied alternating field will accompany the passage of a domain wall through the probe, and may be displayed on a cathode ray oscillograph. With a flat perminvar ring, a circular magnetic field is obtained by passing a current down a wire threading the ring, and an alternating field is supplied through a widely spaced winding on the ring. The circular domain structure may then be found by making the probe move across the ring.

The method has been modified to permit the measurement of the velocity of a domain wall under an applied steady field. Two light probes are focused on the specimen surface at a measured distance apart and a field is applied so that a domain wall passes in turn through the two probes, to give two separate pulses in the photomultiplier output. The time interval between the two pulses can be measured from the oscilloscope trace. Theoretically the wall velocity should increase with increase in the applied magnetic field above a limiting value, and this has been proved conclusively in the experiments I have described, the results

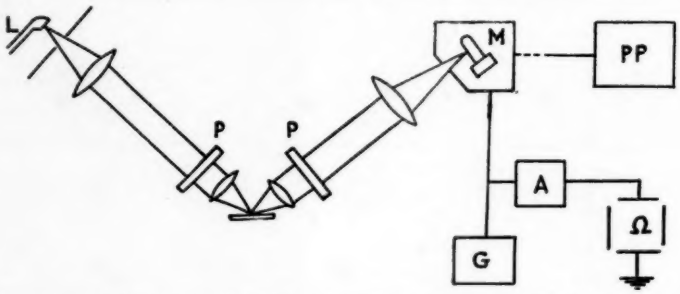


Fig. 3.—Arrangements for investigation of domain patterns with polarised light. L, ribbon filament lamp; P, polaroids; M, photomultiplier; PP, power supply for M; A, amplifier; G, monitoring microammeter.

indicating that the wall velocity is fixed almost entirely by the eddy currents set up in the specimen.

One almost automatically enquires whether the electron microscope or beam technique may not be directly used for the study of domain patterns. The work so far published falls into two main categories. Firstly, we have the pioneer work of Marton at the U.S. Bureau of Standards, in which a narrow beam of electrons passes near the edge of a ferromagnetic crystal and is focused on a photographic plate. The stray fields due to the domain structure produce modifications of the pattern, and Marton and others have used the method for mapping stray magnetic fields and for measuring fields under circumstances where other methods would be difficult, if not impossible, to apply.

Secondly, we have the work of Blackman and others at Imperial College. They limit the primary beam in a conventional electron microscope by a small circular aperture and record the deflections produced at the edge of a ferromagnetic crystal on a photographic plate. Under certain conditions the photograph of the edge of the crystal shows a serrated cycloidal border, which enables the domain spacing to be deduced, together with a second, much larger, cycloidal pattern beyond it. Although the method is complicated and can give only limited information concerning domain structures, it does permit examination to be carried out over a wide range of temperature. It has provided some rather unexpected results; for instance, the domains in haematite have been shown to be much larger than expected.

Such methods do not, of course, yield a direct photographic image of the domains. Spivak and his collaborators in Moscow have attempted to obtain direct photographs, assuming that magnetic inhomogeneities in a surface may form magnetic 'microlenses', and if the surface is a conductor, electric 'microlenses' as well. The secondary electrons, released by the impact of a primary beam on the surface, spiral about the magnetic lines of force of the surface fields, and so provide a degree of contrast when they are focused on a photographic plate to give an image of the domain structure. It is interesting to compare a photograph so recorded with a powder pattern of the same surface. Spivak has also used an electron mirror method designed to increase the interaction of the electrons with the domain fields. The electrons are stopped near the surface and then moved in a reverse direction, with the object of allowing the relatively slow electrons near the surface to be more affected. A few results obtained by this method have been published; they are technically interesting but so far have not increased our knowledge of domain structures. Indeed, Ludwig Mayer has shown that the action of the stray fields is extremely complex and he considers that Spivak's patterns are probably step patterns of the surface.

Kačzer, in Prague, has mapped domains by rapidly vibrating a narrow, pointed strip of thin permalloy sheet of high permeability above the surface on which the domains are formed. A 'pick-up' coil surrounding the probe responds to changes in magnetic induction as the tip of the probe moves transversely above a small portion of the surface, and an amplified current is fed to an oscilloscope to produce a standing line pattern of the magnetic state of the specimen under the path of the probe. I shall not trouble you with a fuller description of the method because it seems to me that it is much more effective in picking out the inhomogeneities or imperfections in a surface than domain structure.

I have mentioned some of these, at present, less successful methods, because it is possible that in the near future they may be improved. The powder pattern technique is still the most powerful one at our disposal, and I propose now to conclude my address by showing you some of the less well-known, but interesting, results which it has given us, concerning the behaviour of thin sheet specimens.

When we take a thin disc of silicon-iron with its surface an approximate (110) plane we often observe a striking lozenge pattern, such as that shown in Plate X (*a*), which is typical of zero or low field conditions. The lozenges are arranged in rows parallel to the [110] direction. When a field is applied along an easy [001] direction, alternate rows of lozenge patterns expand at the expense of neighbouring rows, although domain boundaries may not be seen between the successive rows. It is thought that, in low and moderate fields, the principal domains form layers magnetised alternately in opposite directions, as shown in Plate X (*b*). Since the domain walls make only a small angle with the surface under observation, their intersections with the surface cannot attract a dense line of colloid. The position of a typical lozenge is indicated by *L* in the plate. We think that it is produced by a domain of reverse magnetisation. You saw a good example of such a domain in the film. In Moscow some three years ago, Shur showed a film of such patterns, and he suggested that although they seem to vanish when high fields are applied to the specimen parallel to their long axes, yet in fact they never entirely disappear, but remain as tiny nuclei from which domains of reverse magnetisation may grow when the field is removed.

In many experiments with large grains in thin polycrystalline silicon-iron discs, Dr. Hart and I recorded what we termed 'tadpole' patterns. A good example is shown in Plate XI (*a*). As they usually occurred near the edge of a crystal we considered that they were a special type of closure structure imposed upon a more simple elementary domain structure, and that the 'blobs' or heads of the 'tadpoles' were regions of sharply localised stray fields. Their mode of formation is suggested

in the model, photographed in Plate XI (*b*), in which a large Néel spike closure domain intersects the specimen surface. If the intersection were devoid of any modification, a large surface magnetisation would occur. But this is prevented by a set of small, subsidiary, spikes which reduce the stray flux. These small spikes must be wedge-shaped with small gaps between neighbours; each gap would form a band of surface magnetism and attract deposit, so forming a tadpole. This explanation is, of course, similar to that given for the formation of lace patterns on the sides of a Néel-cut specimen.

A most unusual structure has recently been observed in very thin films of permalloy. The main domain walls, parallel to an easy axis, are crossed at regular intervals by a series of short walls with free ends perpendicular to the main wall, which Goodenough terms 'cross ties'. Dr. C. E. Fuller obtained some excellent patterns on very thin films of iron and nickel-iron alloys. Goodenough explains that these 'cross-ties' are really small flux closure domains which are made possible when the atomic magnetic moments spiral about the axis of the wall.

Finally, I should like to refer to the very beautiful application of the Bitter figure technique to iron whiskers. These are fine hair-like crystals formed by hydrogen reduction of ferrous bromide at 700 to 800° C. In effect, they are perfect, strain-free single crystal specimens, ready made for examination. They can be grown along standard crystal directions as long as 1 cm. and some tenths of a millimetre thick. It is encouraging to note that a Bitter figure pattern on an iron whisker, and an electronmicrograph of a cobalt pattern have respectively provided the frontispiece for an American scientific journal and an English university magazine.

General References

Bates, L. F. "*Modern Magnetism*", Cambridge, U.P., 1951, p. 443.
Kittel, C. "*Introduction to Solid State Physics*, New York, Wiley & Sons Ltd., 1956, p. 414.

(Note. In the course of the address many photographs were shown which cannot be reproduced here on account of space.)

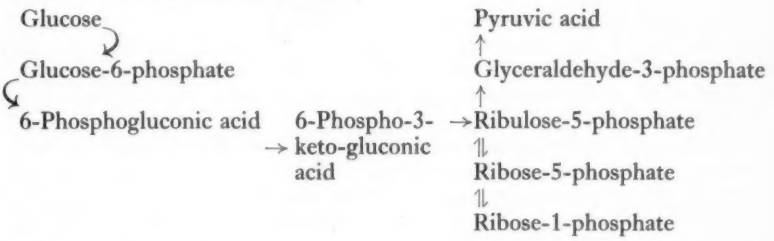
MEDICAL ASPECTS OF CARBOHYDRATES[1]

ADDRESS BY PROFESSOR M. STACEY, F.R.S.

PRESIDENT OF SECTION B

CARBOHYDRATES, generally termed sugars or saccharides, play an essential role in the vital processes of every living cell. They are synthesised in their simplest form from carbon dioxide and water in the leaves of living plants by the agency of sunlight with the catalytic intervention of the ubiquitous and remarkable pigment, chlorophyll. By use of isotopes chemists are now unravelling the precise stages of the carbohydrate interconversions in the photosynthetic cycle. These interconversions involve formation of higher from lower sugars, transformation of one kind of sugar into another, conversion of simple saccharides into di-, oligo- and polysaccharides, hydrolytic breakdown of the polysaccharides and the end combustion of all the saccharides to CO_2 and water. Phosphate esters of sugars including nucleotides, are involved and are concerned with sugar transfers and with the energy changes which are continually taking place in every cell during growth and indeed even after the death of the cell. The transformations are all brought about by Nature's catalysts, the enzymes and their co-enzymes.

Scheme for the degradation of glucose

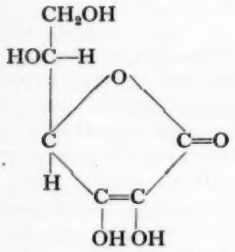


Microbial and animal cells which do not possess photosynthetic pigments must first obtain from plants the simple preformed sugars such as glucose (or grape sugar) which is one of the most important energy sources for the animal body. The difference between the healthy and sick state of an animal or a human may be correlated with the correct and incorrect carrying out of the various carbohydrate transformation cycles. In addition to the general metabolism of the cell, growth and cell division must continuously take place. For these processes complex structural macromolecules must be built to make genes and chromosomes, membranes must be formed and colloidal fluids must be synthesised in order to create the proper environment for the transport of ions and small molecules which are the building bricks for the giant molecules. The carbon atoms of the macromolecules can be provided by sugars and in the main they come from the food eaten by the animal or individual. The most abundant simple saccharides taken in food are glucose from starch and table sugar, fructose from table sugar, and galactose from milk. These 'mono'-saccharides are hexoses containing 6-carbon atoms. In addition fruit pectin provides galacturonic acid which is an acid derivative of a hexose.

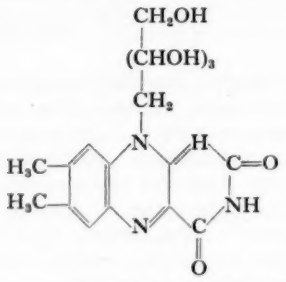
Pentoses or 5-carbon sugars are provided by whole cereals and by the nucleic acids of cells present in all natural foods, especially liver and meat protein.

[1] Address delivered to Section B (Chemistry) on September 3, 1959, at the York Meeting of the British Association.

Carbohydrates play a vital role in the regulation of many of the complex biochemical processes of the body. They may in themselves be vitamins such as vitamin C, the anti-scurvy vitamin present in fruits or they may be parts of vitamins as in riboflavin and the vitamin B_{12} group.



Vitamin C or ascorbic acid



Vitamin B_2 or riboflavin

The proper combustion of glucose in the blood stream of the body is regulated by the hormone insulin of the pancreas and when this fails 'blood sugar' glucose accumulates and diabetes can result. Complex sugars occur as parts of certain hormones such as the gonadotropic hormones and the follicle-stimulating hormone, etc., and they are found combined with protein-like molecules. Some of the steroidal sex hormones occur in the body in association with the important sugar acid, glucuronic acid. This acid also appears to be a most important substance in helping the body to get rid of foreign toxic molecules, such as drugs, etc. It also occurs, as we shall see, in most body tissues as part of the connective material. The sugar, galactose, is an important constituent of the fatty phosphorus-containing components of the brain.

Polysaccharides are important as stimulators of specifically modelled proteins, 'immune proteins', and thereby assist the body in forming defence systems for repelling invasion by parasitic microbes. They also appear to be of importance in the study of the method of attack of viruses, especially those which break down or haemolyse red blood cells.

It will now be appropriate to list some of the essential processes of the body involving carbohydrate molecules and it is hoped to point out how chemical studies of their structure are giving knowledge of great importance in understanding their functioning in both health and disease, thereby adding to medical knowledge. Carbohydrate components of disease producing agents such as bacteria must also be considered.

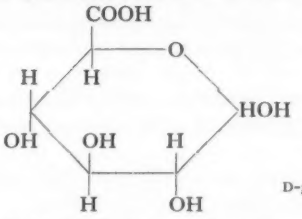
1. General Metabolic Processes

These involve digestion of foods such as starch and sucrose (table sugar) and the absorption of glucose and other sugars; they involve the various carbohydrate cycles and the enzyme systems concerned therein, also the storage and breakdown of glycogen (body starch), conversion of sugar to fat, etc. They involve also the biochemistry of muscle action and the formation of lactic acid.

A great deal of chemical knowledge is now available on carbohydrate metabolism and of the hormones, insulin and epinephrine, which are involved in this. The isolation of insulin and knowledge of blood sugar changes, i.e. glycolysis, has led to the control of diabetes and other metabolic disorders. Recent research is showing that some chemical substances can control glycolysis to some extent and are coming into use as substitutes for insulin in certain cases.

2. Detoxication Mechanisms

Many chemical substances on being given by mouth or by injection to man are excreted in the urine in the form of glucuronosides as in conjugation with the sugar

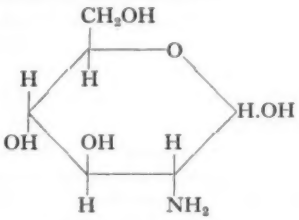


D-glucuronic acid

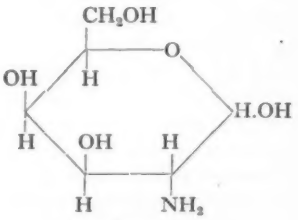
acid, D-glucuronic acid, and this acid plays an important role in tissue chemistry. The conjugation of the foreign molecule probably takes place in the liver.

3. Structural Components

Complex carbohydrates known as mucopolysaccharides and mucoproteins form a very large part of the body's structural material, they form the cell membranes and the connective tissue, they are important in skin especially in the ground substance or inter-layer material, they form the joint substances or lumen, the gastric and intestinal mucins, synovial fluid, etc., elastic and hyaline tissue, lens material and fluid substances of the eye and indeed body fluids in general. They usually have nitrogen-containing units, 'amino sugars', as monosaccharide building units. In lung tissue is found an interesting galactose-containing polysaccharide. Cartilaginous material, e.g. rib cartilage, tracheal cartilage, etc., contains an important group of substances, the chondroitin sulphates which are built from 2-amino galactose and possess sulphate groups.



Glucosamine or
2-amino-2-deoxy glucose



Chondrosamine or
2-amino-2-deoxy galactose

In foetal tissue and in the umbilical cord is a large quantity of the substance, hyaluronic acid, which is very similar to that in ground substances of the skin and many other tissues.

Liver and heart tissue possess various sulphate-containing polysaccharides, among them the substance, heparin, the remarkable blood anticoagulant substance, which keeps blood from clotting inside the body.

Bone and teeth contain mucopolysaccharides as part of the organic structural matrix.

The whole key to the problem of ageing depends on a study of tissue components, since the heart and the arteries are built from them.

As will be shown later, sugar acids and nitrogen- and sulphur-containing sugars are important as constituents of muco-substances.

4. Blood

All the constituents of blood have important carbohydrate components. The red cells or erythrocytes have surface material consisting of mucopolysaccharide-

protein complexes which appear to have some connection with the penetration of the cells by viruses. The white cells or leucocytes contain large amounts of the sugars, ribose and deoxyribose, in the nucleic acid components. Chitin-like substances normally present in insects also can be isolated from red cells. The so-called carbohydrate 'blood group factors' can be isolated from most body tissues. Blood serum consists of albumin and globulin and other proteins and a variety of mucopolysaccharides. The significance of the latter is as yet unknown, except that they increase in certain abnormal conditions. Many muco-substances which are related to mucoproteins and are present in urine, contain amino sugars and galactose as important units.

The γ-globulins are those which contain antibodies or immune globulins, valuable in the so-called immune state of the body.

One of the most important developments of recent years in blood chemistry has been in the field of blood plasma substitutes and a derivative of the bacterial polysaccharide, dextran, has been found to be the best plasma substitute. Its sulphate has also a growing use as a blood anticoagulant.

5. Carbohydrates as Constituents of Antibiotics

This is quite a new field. Carbohydrates have been found to be important constituents of the class of medicines known as the antibiotics and the importance of these is growing. Streptomycin is a typical example, while kanamycin, a recent Japanese discovery, is being rapidly developed in America. The chemistry of these will be discussed later.

6. Carbohydrates as Components of Vaccines

Researches and studies on these form the branch of science known as immunochemistry. The prophylactic prevention of disease by injection of a vaccine is of great importance in present-day medicine. Indeed, in diseases such as smallpox, polio, etc., it is the only way to combat the disease. Vaccines are made either from attenuated living cells or from dead cells such as heat-killed or formalin-treated cells and in some cases it can be shown, as in antityphoid vaccine, that polysaccharide components are essential. All polysaccharides on injection give rise to immune antibody proteins and study of the specific reactions *in vitro* between polysaccharides and immune sera serves to give a great deal of evidence on details of polysaccharide molecular structures. The specific function of hexuronic acid in immune reactions can be strikingly demonstrated.

7. Carbohydrate and Fertilisation Processes

The presence of complex carbohydrate substances forming the envelope which surrounds the egg has led to the necessity for nature to provide for their removal by enzymes. Thus, in many cases, spermatozoa contain powerful enzymes, hyaluronidases, which can break down hyaline tissue and, it is claimed, assist in fertilisation.

8. Carbohydrates of Disease-Producing Agents

Infective disease is caused by microbial parasites such as bacteria, fungi, yeasts, viruses, etc., lodging in the body and pouring forth toxic substances into the blood stream, tissues, etc. All micro-organisms produce complex carbohydrates and these are important in infective disease. Frequently the surface of the micro-organism is surrounded by a gelatinous layer of polysaccharide material, which assists in enhancing the virulence of the parasite. The polysaccharides also play an important role in stimulating the immune antibodies and *in vitro* they react specifically with

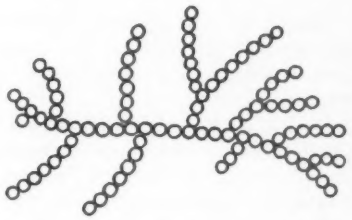
the antibody globulins. Some bacteria contain complex carbohydrates which cause a dramatic rise in temperature of the animal body and these are termed pyrogens. These are even present in drinking water.

It will now be of interest to examine in more detail some of these fields we have listed and to indicate the trends of chemical investigation.

1. Metabolic Processes

These are now all so well known that they have found their way into the text-books of biochemistry and physiology. A lot of research remains to be done in abnormal patients and we have recently been concerned with examining cases of abnormal glycogen storage. Glycogen is high molecular polyglucose having a branched chain structure.

Pattern of Molecular Structure of Glycogen



The outer chains of some glycogen molecules are 6–7 glucose units long, while the interior chains between branch points are approximately 3 units long. Glycogen is built up from glucose-1-phosphate by a series of enzymes, and in some liver diseases—especially in some cases where children are found to have enlarged livers—the glycogen may be found to have an unusual branched structure. In other cases, e.g. of children who are seriously mentally deficient and who have the disease of gargoylism, traces only of glycogen are found but instead the livers have stored fatty material together with a relatively enormous quantity of nitrogen- and sulphur-containing polysaccharides, the structures of which are still unknown.

2. Detoxication

The animal body can make great efforts to rid itself of toxic substances which may be regarded as foreign chemical agents. Usually the tissues contain powerful oxidising agents which can often readily introduce hydroxyl groups into a benzene ring, for example, of a toxic agent. The hydroxyls then become substituted by acetyl or sulphate groups or are coupled to the sugar acid D-glucuronic acid. The substituted compounds are then excreted. Thus menthol given by mouth to rabbits is rapidly excreted as menthyl glucuronoside. Glucuronic acid occurs in many polysaccharides, e.g. tissue polysaccharides, plant gums and pectins, bacterial polysaccharide, etc. It has an extensive chemical literature and it is most interesting reactive substance.

3. The Carbohydrate Structural Substances

Modern techniques are making possible the isolation and purification of these substances and gradually their molecular structures, sizes and shapes are being revealed. Moreover, the methods of their enzymic build-up and breakdown and their biological roles are being elucidated. This work is giving a new look to the chemistry of tissue material and also to the related materials present in micro-organisms.

In addition to acting as cement for holding cells together, the mico-substances may have a protective action, as with skin components, and also a general lubricating

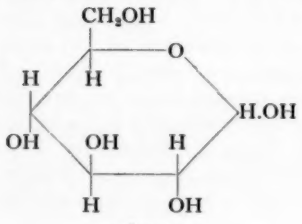
action. Indeed many are associated with movement generally of the parts of animal body. They may be listed as follows:

Movement	*Mucoprotein*
blood movement	serum mucoids
water and ion movement	urinary mucoids
anatomical and muscular movement	joint fluids
	ocular fluids
digestive movement	salivary mucin
	gastric mucin
	intestinal mucin
fertilisation	seminal fluids
parturition	cervical mucins

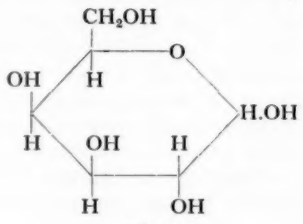
Physically the soluble lubricants form solutions in physiological saline of extremely high viscosity and some form gels at very low concentrations. They have a remarkable capacity for combining with proteins to form highly stable macromolecules.

Both these and the insoluble connective and structural tissue substances are very resistant to all but specific enzymes. In certain disease conditions, e.g. as with certain cysts and ovarian tumours, the mucin may be produced in relatively enormous quantities.

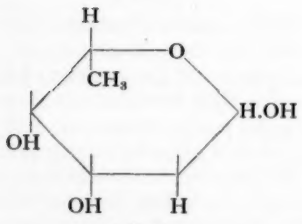
The chemical structures of the major monosaccharide components of these are:



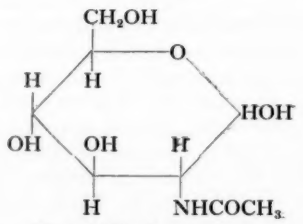
D-glucose



D-galactose



L-fucose



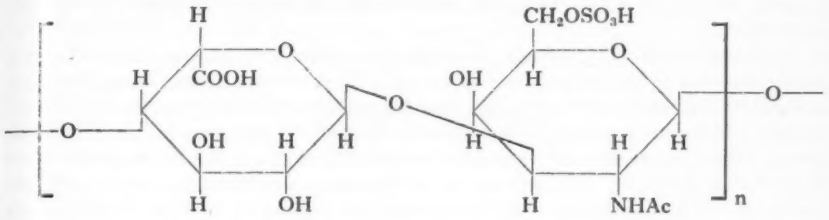
N-acetyl-D-glucosamine

Acetyl residues, sulphate groups and substituted amino, e.g. N-methyl amino, groups may also be present.

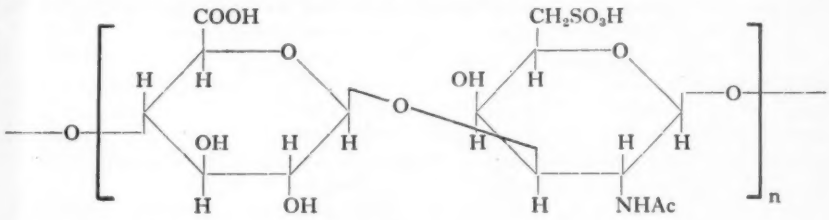
It will now be appropriate to indicate the more important of the tissue polysaccharides and to describe what is known of their chemical structure.

The chondroitin sulphates. These are present in most mammalian cartilaginous tissue and they occur in the form of sulphate esters. They are molecules connected with calcification and salt metabolism and certain pathological states such as rheumatoid diseases involve an upset in the normal synthesis of the chondroitin sulphates. They are present also in heart valves and aorta so that they are also concerned with conditions of ageing.

Chondroitin sulphates, being strong acids with free carboxyl and sulphate groups, form a range of salts with inorganic ions and with proteins and in some cartilages such as bovine nasal septa and trachea, the chondroitin sulphate content is as high as 40 per cent. It is somewhat less in elastic cartilage. In tissues the acid polysaccharides can readily be recognised by metachromatic staining. From different sources three types of chondroitin sulphate, termed chondroitin A, B and C have been recognised. They are closely similar in physical properties but differ slightly in optical properties, e.g. in their infra-red spectra, and they appear to have different monosaccharide constituents. Chondroitin B possesses blood anti-coagulant properties and sometimes is termed β-heparin. It is mainly built up from N-acetyl galactosamine and L-iduronic acid units.



whereas most chondroitins are composed of N-acetyl galactosamine and glucuronic acid units. Structural examination of the molecules assisted by hyaluronidase enzyme studies is now meeting with some success and it appears that chondroitins A and C can be represented structurally as follows:



The position of the other sulphate residues is not yet determined.

Heparin. This is another sulphated polysaccharide of the greatest importance in medicine and surgery. It can be isolated from the tissues of many mammalian organs such as heart, lung, etc., and it was shown by McLean in 1916 to possess the property of retarding or preventing the clotting of whole blood. It is now widely used in post-operative cases and in anti-thrombosis therapy. It is a macromolecule but it forms a crystalline barium salt. A great deal of work has been done on its anti-clotting activity and much is now known generally about the mechanism of blood clotting. The sulphate groups play an important part in this. The major monosaccharide constituents are D-glucosamine and D-glucuronic acid. The exact structure is not yet known but it would appear to be something like this:

[Glucosamine N-acetyl — Glucuronic acid — Glucosamine N-sulphate — Glucuronic acid]$_n$

Heparin B or heparitin sulphate has been isolated from many tissues such as liver and lung including those from patients with various diseases, such as amyloid and gargoylism, etc. It is very similar to heparin but has a very low anti-coagulant activity. The lower sulphate content may account for this.

Chemically modified sulphated polysaccharides of relatively simple structure,

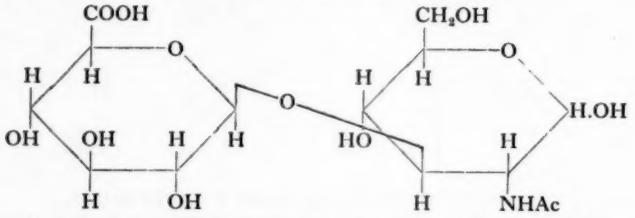
e.g. dextran sulphate, are slowly coming to use as heparin substitutes. With these the molecular size is of the greatest importance.

Chitin. This is a poly N-acetyl glucosamine closely related in structure to cellulose. It constitutes the important skeletal substance of invertebrate species. In crustacea it is highly calcified, while in anthropods it is firmly combined with proteins. In insects it is combined with proteins and with polyphenolic substances similar to tannin. It has not yet been well defined from animal sources, though chitin-like substances are present in red cells. It is produced by higher fungi.

Mucoitin sulphates. These are present in gastric mucosa and in the cornea and consist of high polymers containing D-glucuronic acid, N-acetyl-D-glucosamine and ester sulphate. A related substance, kerato sulphate from the cornea, may not contain hexuronic acids. The detailed structure of these substances is yet to be determined.

Hyaluronic acid. This group of substances occurs in the ground substance of connective tissue and as a colloid plays an important role in regulating the intercellular space fluids, as a cementing substance, as a lubricant generally and as a regulator for tissue permeability. The enzymes, the hyaluronidases, obtainable from venom, spermatozoa, etc., which separate off the protein, break down the molecule and destroy the viscosity of hyaluronic acid solutions, are of great importance in the mechanism of the invasion of tissues by foreign bodies, stings, venom, etc., and in certain rheumatic diseases. They have been applied in dentistry for conveying local anaesthetic rapidly in the gums.

Hyaluronic acid is usually obtained in the form of its sodium salt from umbilical cord, synovial fluid, tumours, vitreous humor, skin, ocular fluids, etc. It also can be produced *in vitro* by various bacteria such as some streptococci. It is a polymer of D-glucuronic acid and D-N-acetyl glucosamine and its repeating unit is probably that of a D-glucopyrurenosyl-β-(1⟶3)-D-N-acetyl glucosamine.



It has a long thread-like molecule having a molecular weight of the order of 400,000. Hyaluronic acid protein complexes are of the greatest biological importance. They have a very high osmotic pressure and regulate intracellular fluids. Synovial fluid is a very efficient joint lubricant for joints which carry high loads at slow movement rates.

Methods are being worked out for the separation of these complex molecules in purified form. Recently we have shown that they can be separated by special resin exchange methods but one of them from bronchial mucin showed how formidable the task is since it contained no less than fifteen different fractions.

4. Blood Carbohydrates

Blood plasma substitutes. A great effort has been made in recent years to make a colloidal substance which would keep up the circulation in patients suffering from severe blood loss, burns, shock, etc. The polysaccharide dextran is now prepared in large quantities commercially for this purpose. It is made from ordinary sugar by fermentation using a Leuconostoc bacteria which produces long straight-chain molecule made up of polyglucose units.

This is treated to give it the right size and shape in order for it to be compatible

with normal blood and it is usually given along with a certain proportion of blood plasma.

The great advantage of this carbohydrate substance is that it can be sterilised and kept for relatively long periods, it carries no virus and does not need to be typed or grouped. It is of the greatest value especially in a state of emergency.

5. Blood Group Substances

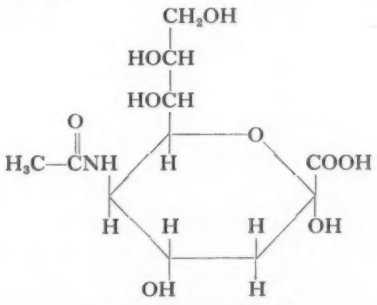
Following the great work of Landsteiner, who discovered that there are four main blood groups, A, B, O and AB, it is now known that there are other blood groups, of which perhaps the Rhesus system is best known. The grouping is of the greatest importance in blood transfusion and in diseases of the new-born. The groups are distinguished by the so-called serological reactions particularly those concerned with the inhibition of the clumping (or haemagglutination) of red cells. The blood group factors reside within the red cells, but closely similar substances can be obtained from a variety of animal tissues such as saliva, gastric mucin, cyst fluids, etc. The blood group A substance can also be obtained from non-animal sources. Purified A and O substances prepared from hog gastric mucin are of high molecular weight and are polysaccharide complexes containing about twelve amino acids with D-glucosamine, D-galactosamine, D-galactose and the so-called 6-deoxy sugar, L-fucose.

$$\left(\text{-L-Fucose} \text{ —— D-galactose} \text{ —— N-acetyl-D-glucosamine-}\right)_n$$

Blood group A substance

In certain preparations it is known that L-fucose forms a terminal group in a chain molecule but little is known yet about the structure of these substances or of the manner in which the twelve or so amino acids are combined with them.

Sialic acid. In connection with compounds containing both amino acids and amino sugars—and such compounds are of obvious biological importance—it has been recognised within the last decade that there exists a family of amino sugars containing nine or more carbon atoms. These were originally termed the 'sialic acids' by Blix, who crystallised a preparation from submaxillary mucin of molecular formula $C_{12}H_{20}NO_9$. The crystals gave specific colour reaction and the same type of material, neuraminic acid, was discovered by Klenk in brain fatty complexes—the gangliosides. The substances are known as the nonulosaminic acids and have the type of formula shown:



N-acetyl neuraminic acid

The acids, although very labile, are now being isolated from a wide variety of tissues and are related chemically by having differing groupings on the OH and NH_2 groups. They can be synthesised by coupling N-acetyl hexosamine with oxalacetic acid. Their importance, also that of their specific enzymes, is undoubtedly growing. Polymers of the acids are now being discovered, especially in

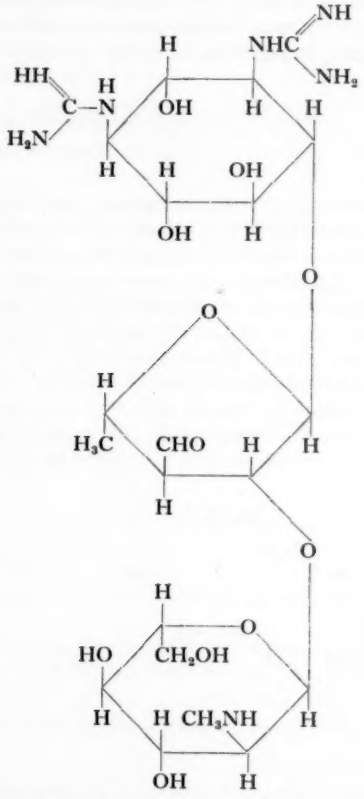
bacteria. Related substances have been obtained from human milk where certain nonulosaminic acids are combined with lactose. These are concerned with the nutrition of human intestinal bacteria flora and are important in infants.

Other similar substances present for example in egg mucin, can prevent certain viruses from causing agglination of red cells and they are undoubtedly concerned with the initiation of infection by some viruses, e.g. influenza virus.

6. Antibiotics

Following the wonderful success of penicillin other antibiotics have formed a new chapter in the treatment of infective diseases. Sugars such as lactose and glucose provide a large part of the raw material from which the antibiotics are made.

It was perhaps to be expected that, in addition, sugars would form part of the molecular structure of some of the antibiotics. Of these, streptomycin is the most important at the present time. This is a complex polyhydroxy body with an unusual branched chain deoxy sugar and a substituted amino sugar forming about two-thirds of its constituents.



Streptomycin

Puromycin contains a 3-amino-3-deoxy-D-ribose, Kanamycin a D-glucosamine while magnamycin contains several unusual sugars. Undoubtedly, carbohydrate antibiotics will become more important. The working out of the detailed chemistry of these substances will add a great deal to the biochemistry of the human body and will lead to new medicines and remedies.

RECENT DEVELOPMENTS AND TRENDS IN PALAEONTOLOGY[1]

ADDRESS BY PROFESSOR O. M. B. BULMAN, F.R.S.

PRESIDENT OF SECTION C

THE last two or three decades have witnessed great progress in palaeontology, as in other branches of geology, and developments which in the opinion of many workers are sufficient to justify them in claiming for it the status of an independent science. My object this morning is to explain something of what palaeontologists have been trying to do; and in offering an address of this kind, I am making a break with the tradition of my predecessors in office, for I am not attempting any original contribution to the subject which I represent. On the contrary, since my survey will be necessarily superficial, I must ask my palaeontological colleagues in particular to forgive the imperfections and omissions in this summary of their work.

Especially since the last war, there has been in most countries a remarkable expansion in academic and museum staffs, and perhaps the ultimate cause of this has been the widespread employment of palaeontologists in the economic field—palaeontologists, moreover, whose own activities have increasingly embraced original research. The many new journals partly or wholly devoted to palaeontology which have been established all over the world reflect the greatly accelerated output of research. And since ours is essentially a descriptive science, one of the biggest problems confronting the conscientious teacher is how to deal adequately with this geometrical increase in the store of palaeontological knowledge. There is no doubt that we expect more of our graduate today than was required of us at the end of a similar period of training thirty or forty years ago. Nearly every major group of fossils has been intensively studied; many (like the goniatites, the Coal Measure 'mussels', or the ostracods) have come into unexpected prominence as important stratigraphical indices; and scarcely one but has lately acquired an entirely new and incidentally far more complicated classification. Several groups have been assigned to new and unfamiliar places in the animal kingdom; and the changes in nomenclature, quite apart from the vast numbers of new genera, are bewildering in the extreme to those who have had little occasion to keep in touch with the literature of the subject. New branches of study, like palaeoecology or palynology, have been initiated; a working knowledge of statistical methods and modern genetics is taken for granted; and some of our ideas on evolution have been considerably modified.

In pursuit of these activities, the palaeontologists is, in no derogatory sense, an opportunist; for he has far less freedom than the neontologist to plan his investigations, and his advances depend more often upon chance. Thus they depend very largely upon the discovery of new material, which can rarely be deliberately planned. They depend also upon the application of techniques, which may be developed or borrowed from other sciences. And from the very nature of the fossil material with which he deals, the palaeontologist's interpretation of it is bound to reflect his assimilation of current developments in zoology and genetics. Particularly characteristic of the immediately post-war years have been the many attempts at constructive syntheses of palaeontology and allied sciences, especially in taxonomy and in the realm of evolutionary theory; and with this, a healthy reassessment of the evidence for much that had become almost dogmatic.

[1] Address delivered to Section C (Geology) on September 7, 1959, at the York Meeting of the British Association.

I. New Sources of Information

New Material

Although the discovery of new material is unpredictable, owing to the nature of the stratigraphical record, it is fortunately an almost inevitable consequence of systematic collecting.

For instance, forty years ago all that was known of the Cambrian trilobite fauna could be accommodated in about a dozen families, and most geologists were content to cite *Olenellus* as entirely typical of the Lower Cambrian. In Hupé's recent classification of the trilobites, sixteen of his twenty-five Superfamilies (two-thirds of them) are mainly Cambrian, and nine make their appearance in the Lower Cambrian; whilst of a total of just under 1,000 genera, more than half are Cambrian and over 10 per cent are Lower Cambrian genera. This advance, which has hardly been fully digested as yet, reflects little other than the discovery, in various parts of the world, of new material from a hitherto, little-known part of the geological column.

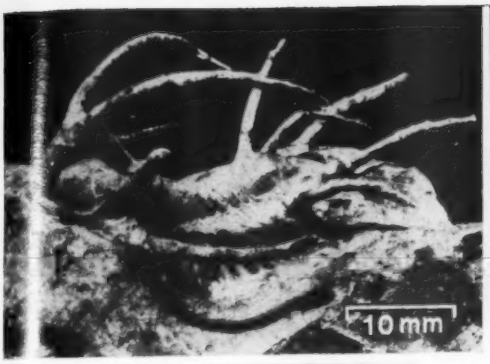
Again, Kozlowski's wonderfully detailed investigation of the structure of the dendroid graptolites, which has entirely revolutionized our ideas on graptolite morphology and relationships, is a notable example of opportunism. It exploited his discovery of material in a near-perfect state of preservation, and owed far more to this than to any intrinsic novelty in the techniques employed; in fact, the basic techniques used by Kozlowski scarcely differed from those used by Wiman fifty years earlier.

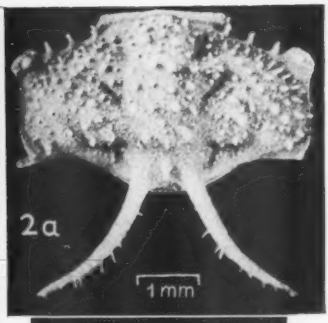
Techniques

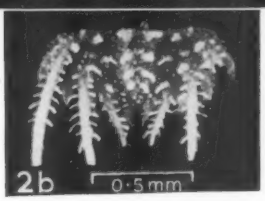
Technique now plays a far greater part in palaeontological investigations than ever before, involving the preparation of fossils, their illustration, and the handling of data. No palaeontological laboratory today is without its assorted chemical supplies, and elaborate equipment, such as microscopes, cameras, grinding apparatus and the like, is taken for granted; the change in attitude can perhaps hardly be appreciated by our younger workers. Moreover, it supplements the discovery of new material by re-vitalising much that already lies in museum drawers.

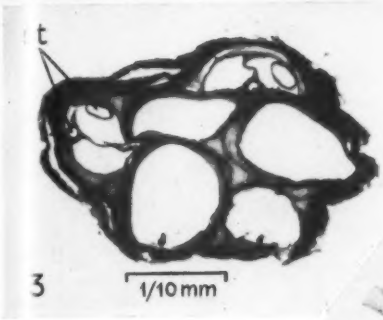
Preparation of material. The amount of preparation necessary varies with the purpose of the work in hand, and much stratigraphical palaeontology still makes only slight demands; but all the better morphological and palaeobiological work is now characterised by extensive and often time-consuming preliminary preparation designed to eliminate the enveloping matrix. However, the basic methods remain relatively little changed; what is so distinctive is the scale on which these methods are now applied, and the range of material that has been obtained by them from both new and old collections. For a large proportion of our material, mechanical methods of preparation (Fig. 1) cannot be superseded, though here the introduction of vibro-tools and, above all, the greatly improved binocular microscopes and high-intensity lamps have undoubtedly raised the general standard. The differential solution methods, too, are nearly all based on techniques initiated more than half a century ago, including the use of HCl, HF and acetic acid, and various 'transfer methods' of backing fragile fossils; but acid is now used in bulk, and fossils are liberated by thousands (Figs. 2–4). Moreover, a judiciously speculative use of solution methods has been amply justified by the revelation of microscopic material, such as plant spores, conodonts and holothurian spicules, in a diversity of rocks. Allied to these have been successful developments in breaking-down relatively unconsolidated rocks so that their undamaged fossil content can be concentrated by washing and sieving.

To neutralise a hard matrix by serial sectioning, where the fossil can neither be dissolved out nor dissolved away, is again no new discovery: Sollas designed and used an apparatus capable of grinding serial sections at one-fortieth millimetre









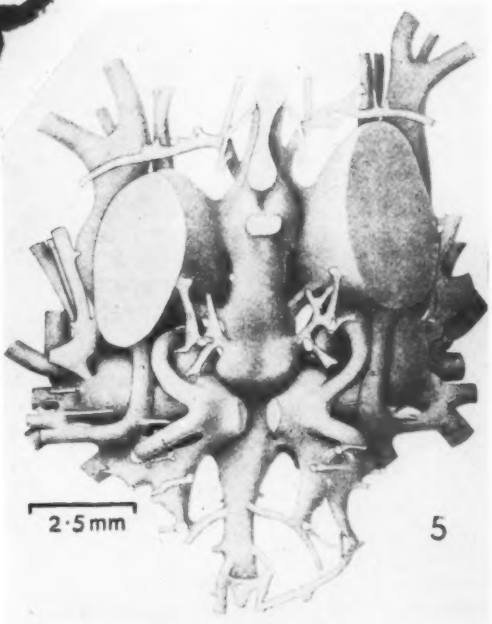


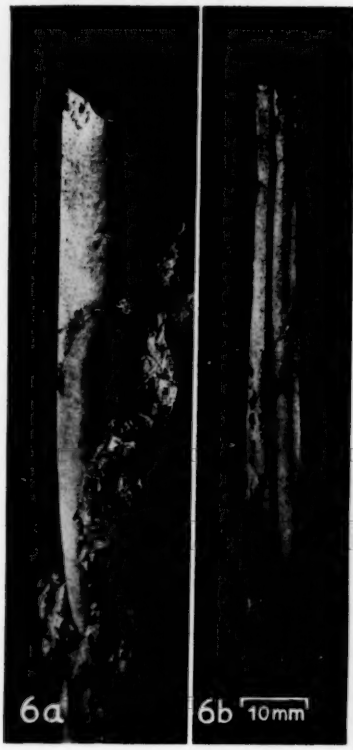
Fig. 1.—A notable example of mechanical preparation: the spined trilobite *Ceratarges* (side view) preserved as calcite in a hard Devonian limestone.

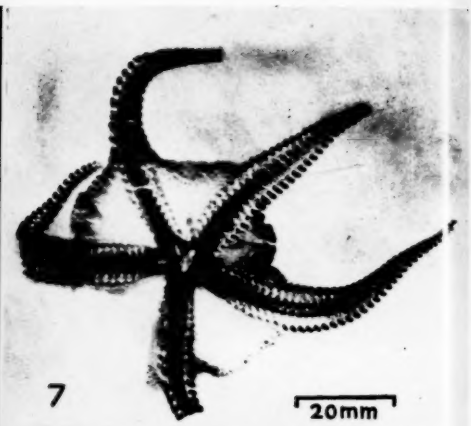
Fig. 2.—Portion of the head-shield and larval tail of a silicified Ordovician trilobite (*Ceratocephala*) obtained by differential solution with HCl from a limestone matrix (photographed against a black background).

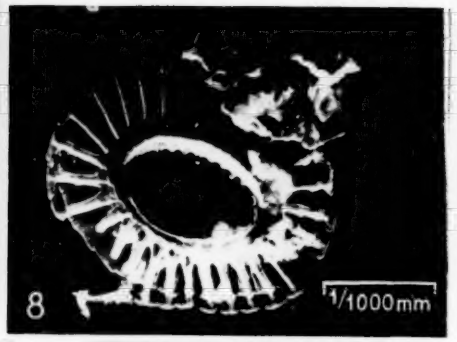
Fig. 3.—An 8μ microtome section through the branch of a dendroid graptolite (*Koremagraptus*) obtained by successive HCl and HF treatment of an impure Ordovician limestone, and embedded in collodion. The periderm, which has not been cleared, shows its layered structure; two of the four internal stolons seen in section are lettered *st* (Transmitted light).

Fig. 4.—The external skeleton of a biserial graptolite (*Amplexograptus*) obtained by differential solution with HCl from an Ordovician limestone. The slightly carbonised chitinous periderm has been cleared with HNO_3 and $KClO_3$ to reveal the growth-bands of which it is composed (Transmitted light).

Fig. 5.—A wax model of the brain cavity, orbits, semicircular canals and associated structures of the primitive fish-like *Cephalaspis* (Devonian) constructed from serial sections ground through the head-shield.







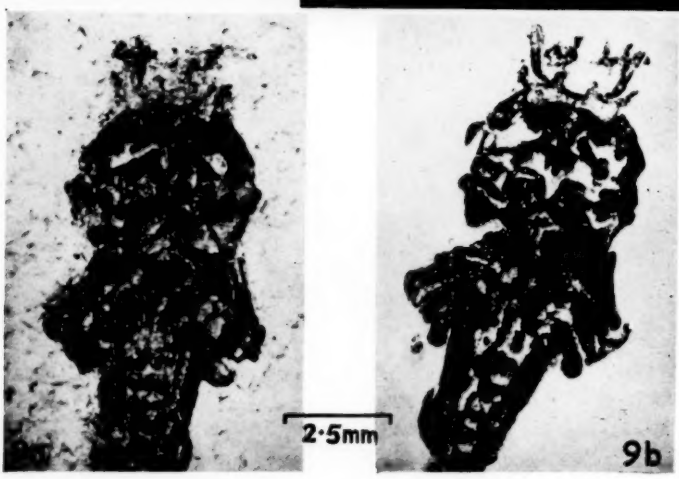


Fig. 6.—Lateral (6a) and ventral (6b) views of a rubber latex cast of a belemnite preserved simply as a natural mould in a Cretaceous sandstone. The rubber latex has been whitened with NH_4Cl before photographing.

Fig. 7.—X-ray photograph of a pyritised Devonian starfish (*Encrinaster*). The specimen, embedded in slaty matrix, was only partially exposed and no preliminary attempt was made at mechanical preparation or cleaning.

Fig. 8.—Electron micrograph (carbon replica, chromium shaded) of a coccolith (*Coccolithus huxleyi*) from the Globigerina Ooze (Challenger Expedition).

Fig. 9.—The head of the problematical Devonian fish-like *Palaeospondylus*, photographed (9a) immersed in xylol, and (9b) in α monobrom-naphthalene with infra-red filter and plate, illustrating the use of high RI liquids in photographing fossils.

intervals as long ago as 1903, and Stuart Weller systematically applied serial sectioning to the description of Mississippian brachiopods in 1914. But with the introduction of various more efficient forms of grinder, the method is now regularly employed in many groups of organisms, and has become almost routine procedure in the study of articulate brachiopods. For the interpretation of sections through really elaborate anatomical structures, the laborious preparation of wax or plaster reconstructions (Fig. 5) cannot be avoided, but for simpler structures we can adapt the more rapid method of contour diagrams and the block diagram of the geologist, or consider it adequate to figure selected sections.

If all these methods remain much the same, however, a notable innovation has been the introduction of plastics, not only for the impregnation of fragile fossils and for backing in solution methods, but for the making of moulds. In particular, the use of flexible plastics, as well as rubber latex, in taking undercut moulds has not only revolutionised the whole process of casting, but has made available for detailed morphological study a wide range of hitherto quite unproductive fossil material (Fig. 6).

It is perhaps surprising that physical techniques, such as X-ray photography, have been so little exploited. X-rays have been used—with considerable effect where the fossils are pyritised (Fig. 7)—but the results are generally lacking in fine detail. Nevertheless, it is obvious that they have potential value for revealing internal structures where a specimen cannot be sacrificed for sectioning and other methods are inapplicable. Electron microscopy, however, promises to have fundamentally important and widespread applications to palaeontology in the near future (Fig. 8). Other physical techniques, such as lead/uranium, radiocarbon and fluorine dating, and temperature determinations from oxygen isotopes, have only an indirect bearing on the present subject.

All these preparation techniques are making available a wealth of detailed morphology, demanding in turn more exacting standards of description and a really adequate knowledge of the anatomy of living forms. In this respect, it must be admitted, the standards of invertebrate palaeontology are still apt to compare unfavourably with those of vertebrate palaeontology.

Illustration. Of equal importance to the palaeontologist are the techniques of illustration. Thirty or forty years ago, we had seen the disappearance of the professional draughtsman, and the beginning of the photographic era. At first, any gain in accuracy was generally more than offset by loss of clarity, even with expensive collotype reproduction, for the average standard of photography was frankly bad. But the whitening methods initiated by Ulrich (Fig. 6); the use of various high refractive-index liquids (Fig. 9) pioneered by Stensiö; and the general improvements in lighting and photographic equipment are making possible a much higher quality in photographic illustration.

Handling of data. Certainly one of the most striking of recent innovations has been the use of quantitative and biometric methods and the statistical analysis of so-called fossil populations. Sometimes the results of such methods have hardly justified the labour involved, and they are at times apt to appear more reliable and objective than is warranted by the quality of the data employed. Nevertheless, it is now recognised that statistics can be the best and even the only means of interpreting and describing certain features of evolution. Such methods, however, supplement rather than replace the older qualitative palaeontological methods. Their main limitation lies in the kind of data that can be handled; the more subtle differences in shape are not fully expressed by simple height, length and breadth measurements, and external form is but a small part of the whole complex morphology of an organism. Some indication of the complexity of the statistical techniques that may be necessary even for linear dimensions may be gauged from the fact that in his revision of *Micraster* evolution, Kermack's measurements were limited to a

collection of urchins from a single locality and horizon; and of course this biometric study could not include such features as the granulation of the test or the suturing of the ambulacra (upon which the working palaeontologist commonly relies). But the value of the objectivity of even a simple statistical treatment in checking an evolutionary series is brought home to us by Joysey's review of the evolution of *Gryphaea*. Furthermore, the reliance placed upon simple statistical techniques by workers on non-marine lamellibranchs, for example, is sufficient indication of their practical value.

Micropalaeontology. I cannot conclude these observations on techniques without some reference to micropalaeontology, which has acquired such popularity in the last few years, has given its name to a flourishing journal, and even figures largely in some university curricula. But it is a popularity that many of us deplore in so far as it becomes a 'restrictive practice'. The plain fact is that 'micropalaeontology' is not a distinct scientific discipline. The ostracods are, after all, Crustacea; and the Foraminifera are Protozoa, and it represents no real advance to treat them out of their proper context. Indeed, it seems to be overlooked that the ontogenetic study of any group of sizeable animals involves a transition from so-called micro- to macro-palaeontology. Nor, as Cooper has pointed out, is a cohesive science produced by restricting attention to certain small fossils which happen to possess economic value. Moreover, there is a real danger that the popularity of micropalaeontology, resulting from the technical needs of industry, may lead to an unfortunate lack of balance and the neglect of many important fossil groups.

Micropalaeontology is, however, a veritable constellation of techniques: techniques for the solution or disintegration of the matrix, for the extraction and concentration of minute organisms, and for the handling and mounting of them. Above all, the number of individuals handled is so great that sampling techniques become necessary, species distribution within the assemblage becomes significant, and specific variation assumes such importance as to require statistical presentation. Few so-called macropalaeontologists handle individuals of a single species in comparable quantity.

II. Some General Results

From this summary of the methods by which our basic facts are being accumulated, I pass to what must be an equally brief review of some developments and changes of opinion in the science of palaeontology itself. And at the root of all these lies that exasperatingly abstract concept of the nature of species and the relationships of species to one another in palaeontological or evolutionary series.

Palaeontological Series and the Species Concept

As long ago as 1899, Rowe had initiated the layer-by-layer method of collecting series of related fossils, and by his investigation of the Chalk sea-urchin *Micraster* had established the first reputable lineage among invertebrate fossils. This work was followed a decade later by that of Carruthers on the Carboniferous coral *Zaphrentis*, and at the beginning of the interwar period by that of Trueman on the Liassic oyster *Gryphaea*. The significant feature common to all these was the variability shown by the specific assemblage at any given horizon; and it focused the attention of palaeontologists on the assemblage, which approximates to the living population or community, rather than on the individual. The evolution of one species from another was seen to be, not a process in which all specific characters advanced equally and in step with one another (something which could be represented in a diagram by a single line), but a process which could only be represented by a plexus of anastomosing and interlacing lines. Palaeontologists owe this formulation of the descent-plexus to Swinnerton, and it was elaborated in Trueman's classic analysis of the *Gryphaea* series.

There is, however, some risk of confusion in this simple presentation of the plexus metaphor, and one of the clearest expressions of its more exact relationships is that given not long ago by Simpson in the diagram reproduced below. In this, *A* represents in much simplified diagrammatic form the anastomosing pattern of sexual reproduction in a succession of generations in one population; *B* represents equally diagrammatically the spliced and interlacing strands of the various populations and communities that go to make up the whole species; and *C* is the line of descent as commonly shown in our simplified phylogenies.

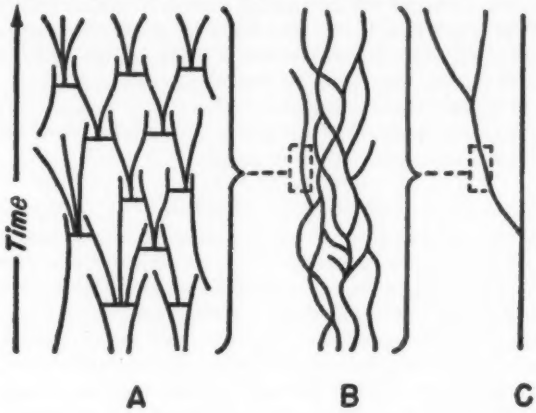


Fig. 10

To the palaeontologist, it follows that a species is a section or length of this multistranded 'rope', arbitrarily defined by upper and lower time boundaries. Only at a single instant of time is it a cross-section of this rope—a series of points (representing the separate individuals) enclosed within the enveloping specific diagnosis. This concept of the lineage-plexus and what has since been called the chronospecies—the segment of rope—constitutes the outstanding development in palaeontological thought of the interwar years. It is the "New Palaeontology" of Lang (1940) and it underlies all subsequent speculations on species and on evolution in palaeontological literature.

Much work in the postwar years has been concerned with the re-examination of these palaeontological series, their interpretation, and their bearing on theoretical systematics. Kermack has submitted part of Rowe's *Micraster* series to a rigorous statistical analysis; Joysey has reviewed more objectively the basis of Trueman's *Gryphaea* series, with somewhat disconcerting results; and there have been innumerable discussions on the species problem in all its theoretical complexity, generally involving a wealth of hypothetical examples. That no new series has been introduced perhaps underlines what I said at the outset about the difficulty of obtaining results 'to order' in palaeontology, and demonstrates how little evolution has actually been traced as yet in invertebrates. Quite apart from a certain monotony there is a obviously very real need for fresh examples and additional evidence, more precise and exact than has sufficed in former years. This is one of those fields where theory has tended to outstrip factual basis. As Errol White observes in his foreword to a valuable symposium on the species problem: 'Fresh breezes are doubtless blowing through the musty halls of orthodox palaeontology, but some of us may be forgiven for thinking that in places the amount of wind is excessive.'

No one can delve far into this palaeontological literature on the nature of species without becoming conscious of the conflict between the theoretical and the practical—between the ultimate philosophical entity (what Darwin called the

'undiscoverable essence of the term species') and the practical unit of the working palaeontologist or zoologist. To bring palaeontological evidence into the evolutionary picture at all, it is clearly necessary that the species should be defined in current evolutionary terms. In fact, the evolutionary palaeontologist is striving to recognise amongst fossil material something strictly comparable with the living species population, spurred on by his appreciation of the vistas which would then lie open in the interpretation of the palaeontological record. On the other hand, the 'working palaeontologist' (and by that is generally meant the stratigraphical palaeontologist), inundated by the continuous stream of material sent for identification, is prepared to argue that his species must be essentially subjective and even that the only logical criterion for its definition is its usefulness (Arkell). As G. S. Carter has pointed out, the species so defined loses any significance as an evolutionary category. Between these attitudes there can be no compromise; the problem concerns the zoologist just as much as ourselves, and the two systems will inevitably co-exist for a long time to come.

Taxonomy and Systematics

Attempts to recognise something comparable with the biospecies among palaeontological material have had their effects in the purely taxonomic field also. Forty years ago, it was still exceptional for a systematist to designate a type specimen. The need for greater precision and a more universal regard for the rules of nomenclature have made it a routine practice today. But after the last war, it was suggested that even this was inadequate to define a species and Simpson proposed the substitution of what he called the hypodigm. This was in effect a proposal to incorporate in the definition of the species every specimen that its author was prepared to assign to it; and it had the support of many statistically-minded palaeontologists; but whatever theoretical arguments may be adduced in its favour, the practical difficulties have proved so great as effectively to prevent its adoption.

From an evolutionary standpoint, the species problem is the kernel of our taxonomic problem: this is the level at which evolution occurs: the genus is frankly arbitrary and subjective. But to the systematic palaeontologist, influenced alike by the limitations of fossil material and by expediency, it is often the genus which is the more readily defined category. However that may be, families and groups of higher taxonomic rank are entirely subjective; and one of the really remarkable features of recent palaeontology has been the collapse one by one of the classifications of various classes and phyla of invertebrates that were current twenty years ago or even less. The trilobites, brachiopods, nautiloids and echinoids are perhaps the most conspicuous, but hardly any have escaped. Generally speaking, the old classifications operated rather in the manner of a key; they were commonly based on a single character—such as the course of the facial suture, the nature of the siphuncle, or of the pedicle foramen—often supported by theoretical considerations that have since proved valueless or even erroneous. Those which replace them are generally constructed on the opposite principle, gathering together seemingly related groups of genera into higher and higher categories, always utilising as many of the total characters as possible. The result is usually a far more complicated scheme, with a large number of more or less equal categories of high rank. Thus the five orders of nautiloids are now replaced by fourteen; the three orders of trilobites by twenty-five superfamilies; or the two sub-orders of articulate brachiopods by fourteen sub-orders.

What still remains to be accomplished, however, is a more harmonious fusion between palaeontological and zoological interests in several of these classifications. In the past, the zoologist has too often based his classification on features of the soft parts which left no recognisable trace in the skeleton, and appeared little concerned with the multitude of extinct forms thus left homeless. The gastropods,

lamellibranchs and ostracods are well-known examples. The palaeontologist, on the other hand, was compelled to rely on skeletal features which may have seemed to the zoologist of minor importance, and often tended to ignore the problems presented by the living animal.

Fortunately, the zoological classifications were frequently as arbitrary and unsatisfactory as their palaeontological counterparts, and many are similarly in process of revision. The chance for collaboration is therefore at hand and there is reasonable hope that the need for it is being appreciated on both sides. Certainly the latest gastropod classification owes much to the palaeontologist and offers a framework within which he can operate; and the remarkable discovery of *Neopilina*—a discovery even more dramatic than the coelacanth *Latimeria*—has served to focus attention on the importance of palaeontological evidence in the invertebrates. Among lamellibranchs also, the palaeontologically valueless 'gill classification' is being replaced by one which can embrace extinct as well as living forms.

Recapitulation

In the interpretation of evolutionary mechanism, palaeontologists naturally recognise that they are in no position to make a distinct contribution, and must accept whatever views happen to be current among zoologists. Thus the inheritance of acquired characters is not something that can be proved (or for that matter disproved) in palaeontological material. Even the difficulty of deciding whether or not a character may have possessed adaptive or selective significance is far greater with fossil than with living organisms, though a functional significance can often be deduced with some objectivity. The Lamarckian interpretation that was so popular in palaeontology in my student days has been superseded, and with it much of the dogma of recapitulation. At the beginning of the interwar period, the views originated by Haeckel (that the individual, in the course of its own development, recapitulated in essence its phyletic history), and popularised by Hyatt and Beecher, were still unquestioned except by the lone voice of Spath. That the evidence had been grossly overstated: that in some instances the alleged phylogeny had actually been based on the ontogeny which it was claimed to control: can scarcely be denied. And in the 1930's, the revolution which relegated recapitulation to a relatively minor category in a wide range of ontogeny/phylogeny relationships had made itself felt in palaeontological literature.

Today, the zeal for proterogenesis and the precocious appearance of phyletically significant characters may be carrying us too far in the opposite direction. As with orthogenesis, the ultimate proof or disproof of all ontogeny/phylogeny relationships lies fairly within the field of palaeontology; but we shall not get much further without additional well-documented phylogenies, based on rigid stratigraphical control, together with more precise information on the ontogeny of the species concerned. Moreover, an appreciation of the lineage-plexus and evolution through communities has, as pointed out by Swinnerton, a decided bearing on the concept of recapitulation.

Ontogeny and Allometry

Palaeontologists have been quick to appreciate the special possibilities offered by another aspect of the study of ontogeny, namely, relative growth or allometry. Although actual growth-rates are outside the scope of palaeontological study, the complicated differential relations which as J. S. Huxley showed frequently underlie the growth of various parts of an organism in relation to the whole, are independent of absolute time, and these open up a new field of investigation. Much work has already been done, especially among fossil arthropods (trilobites and ostracods in particular); and among vertebrates still more ambitious studies have been made into the relationship between differential growth rates in ontogeny and differential

changes in phylogeny. Robb's original conclusion that in the evolution of the horse skull the allometric relationships have remained constant throughout the Tertiary, may be an oversimplification (Simpson), but he established the fact that relative growth is an essential factor in phyletic evolution. Curiously enough, such methods have as yet been but little applied to that vast range of invertebrate fossils whose shells result from accretionary growth, and where in consequence there can be no dearth of young stages. That quite complicated changes in growth-rates in different directions are responsible for a wide variety of shell form has been shown for example by Rudwick's recent analysis of shell growth in brachiopods; and Eagar has demonstrated relative-growth differences between specific communities of *Carbonicola* from different localities.

Orthogenesis and Trends

Like recapitulation, the various theories of programme evolution and orthogenesis did not originate with the palaeontologist, but again they were enthusiastically adopted and their rise and decline has been another of the notable changes in palaeontological thought during the last two or three decades. Orthogenesis has been used in many different senses, but essentially the theories represented attempts to account for straight-line evolutionary changes which seemed unconnected with environmental conditions, and in some cases appeared to be carried beyond the bounds of efficiency. Characteristically also they were to be seen in more than one evolutionary series or lineage. It was for such independent but parallel evolutionary changes, contemporaneous or of different ages, that the term 'trend' was introduced by Lang. The general existence of such trends is undoubted; it is their interpretation which is in question. The palaeontologist (and I have myself been guilty) commonly appealed rather vaguely to innate constitution and inhibiting factors, and the term orthogenesis has become 'tainted' with a vitalistic interpretation, although this was rarely intended, and indeed, as Trueman observed, an innate cause may be the genes themselves.

Many examples, particularly among the vertebrates, have since been shown to be completely ill-founded, or for one reason or another can preferably be given a more orthodox explanation. Some, such as the grotesque skull development of Osborne's *Titanothere* series, can no doubt be regarded as a natural consequence of allometric growth coupled with phyletic increase in size—itself an important trend. But there remain others which would repay a more critical analysis before ortho-selection can be claimed either to explain or to fail. Among these are the well-known graptolite examples, although here too some of the series commonly cited are in my view erroneous and the published data call for extensive revision before any reinterpretation can be profitably attempted.

Evolutionary Rates

One of the results of a somewhat more reliable U/Pb dating of the stratigraphical column has been to make possible some provisional calculation of the actual rates of evolution. This distinctively palaeontological contribution to the study of evolution owes much to the initiative of Simpson and has so far been mainly explored in relation to fossil vertebrates. Here we are concerned with the evolution of a single phylum, within which the main classes appeared in orderly succession through Upper Palaeozoic time, and some orders of which have had their evolution traced in considerable detail. Simpson distinguishes at the outset between 'morphological rates' and 'taxonomic rates'. Morphological rates concern the rate of change of single characters or groups of characters in a lineage, such as various features in the evolution of the skull in the horse series through the sixty million years of the Tertiary. Taxonomic rates are concerned either with the duration of successive genera in a lineage (which Simpson calls a phylum), which gives a measure of the

'phyletic rate', or else are based on counts of the number of genera (or other taxonomic units) at successive periods, which gives a 'taxonomic frequency rate': this is a rough measure of evolutionary activity.

Amongst the various invertebrate phyla, little comparable work has been attempted and the difficulties are greater. The classes within a phylum are not so clearly related, and the evolution of classes and orders is far more obscure. It is not at all certain to what extent conclusions drawn from the study of fossil vertebrates are applicable to the invertebrates, and comparisons between vertebrate and invertebrate taxonomic frequency rates seem at present to be rather misleading. The nature of the 'genus' is arbitrary; the number of genera recognised at different horizons closely reflects the particular interests of the active systematists; and Alwyn Williams has shown how much depends upon selecting even approximately comparable evolutionary climaxes. A group claimed to evolve seven times as fast as another by one investigator can, as a result of corrections applied by another investigator, be said to evolve at approximately the same rate. In fact, the comparative value of estimates of taxonomic frequency rates will obviously be greater when restricted to orders within a single class. Morphological rates, on the other hand, are more likely to provide interesting and valid comparisons between different classes and phyla, and these have scarcely been touched on as yet.

With the accumulation of quantitative data on rates of evolution, it should become possible to investigate rather than merely speculate upon the relation between organic evolution and crustal movement, and a symposium on this topic was published by the Palaeontological Society of America in 1952. There are of course as many geological as palaeontological difficulties to be surmounted and the diastrophic theory itself would be regarded by most geologists as an oversimplification. 'Evolutionary bursts' and surges are a well-recognised feature and the distribution pattern of most invertebrate groups tends to be nodal; but no evidence has yet emerged that periods of evolutionary expansion in different groups coincide, or that there is any obvious correlation with periods of pronounced earth movement. Most palaeontologists would probably agree that earth movements have not had any general overall effect in stimulating evolution; but epeirogenic movements must necessarily alter submarine environments and affect land connections, and thereby influence the faunal succession.

Ecology

A general interest in the environment of fossil animals has always animated palaeontology, but the intensive study of palaeoecology as a separate branch of the science is again something comparatively new. Petersen's pioneering work on present-day bottom faunas of the Kattegat was introduced to geologists by Miss Elles in her address to this Association in 1923, and the subsequent growth of scientific ecology has been fully reflected in geological literature as witness the two massive volumes published a year ago by the Geological Society of America. The topics included in palaeoecology bear mainly on stratigraphical palaeontology, and that field, covered in Dr. Stubblefield's address a few years ago, I have intentionally excluded. But there is of course a more strictly palaeontological aspect of ecological relationships to be considered.

The concept of adaptive radiation, long recognised in vertebrate evolution, involves the occupation of an environmental zone, sometimes previously empty and sometimes by successful invasion of a zone already occupied, and is recognised as an important factor in the development of higher categories of animals. Adaptation within the broad zone to successive narrower zones or niches accompanies the differentiation of lower categories. The process has been described in detail with a wealth of vertebrate examples by Simpson. Its application to the invertebrata

has been slow, yet its bearing on their evolution and classification is equally important. Douville's classification of the lamellibranchs, modified and adapted by Morley Davies thirty years ago, was broadly based on such principles, which also underlie much modern work on living lamellibranchs. A necessary corollary to its detailed application is the functional interpretation of morphology, which in fossil invertebrates has been strangely neglected, perhaps as a reaction against a too readily subjective interpretation. But as Rudwick has shown, the validity of such interpretations can be tested by perfectly scientific methods. In fact, functional analysis of morphology in invertebrate fossils promises to become one of the most rewarding fields of investigation.

It is obvious that some of the most important developments I have thus briefly outlined—our concept of species, our views on evolution, our interpretation of phylogeny and ontogeny—owe much to the assimilation of contemporary discoveries in zoology and genetics. Clearly we must make more provision in future for a really adequate zoological training within the palaeontological curriculum. But it would be wrong to present the science as a mere mirror reflecting zoological thought; we have a distinctive contribution to make which is assured by our geological connections. Palaeontology alone among the biological sciences incorporates the time dimension and introduces the concept of tempo in evolution. It alone can show what evolution has actually occurred in the past; and nowhere else can we look for any evidence concerning the origin of the higher categories of animals—classes, orders, and families. Thus it is the source of all phylogeny.

Our indispensable relation to stratigraphy will almost inevitably ensure that the main output of palaeontological research continues to lie in the fields of stratigraphical palaeontology and routine systematic description. But as Hawkins forecast in his address to this Association in 1936, the distinction between neontology and palaeontology is fading, and from their fusion will arise what Simpson has called the 'science of four-dimensional biology'. This is going to demand a somewhat different outlook and training from that normally associated with either geology or zoology.

Along whatever lines palaeontology may develop, however, no serious palaeontologist would deny that morphology must remain its basis and the foundation of all training. Any tendency, in the pursuit of particular interests, to regard that as outmoded is both short-sighted and dangerous. If my address has a moral, it is that in palaeontology, where the temptation to generalise is no less strong than in most sciences, successful generalisation rests on the most exact and detailed morphological investigations which contemporary techniques will allow.

ACKNOWLEDGEMENTS

Fig. 1 is from RICHTER, R. and E. (1930): *Natur und Museum*, **60,** 31.
Fig. 2 from WHITTINGTON, H. B. & EVITT, W. R. (1954): *Geol. Soc. Amer. Mem.*, **59.**
Fig. 5 from STENSIÖ, E. A. (1927): *Skr. om Svalbard og Nordishavet*, No. 12.
Fig. 7 from LEHMANN, W. M. (1938): *Jahresber. und Mitt. Oberrhein. geol. Vereines*, **27,** 16.
Fig. 8 from a photograph by MRS. B. A. G. BARNES.
Fig. 9 from HARRIS, J. E. & LATHAM, E. (1951): *Med. and Biol. Illustration*, **1,** 130.
Fig. 10 from SIMPSON, G. G. (1953): *The Major Features of Evolution.*
The remaining figures have been supplied by my colleagues at the Sedgwick Museum.

MAN AND THE WORLD'S FAUNA[1]

ADDRESS BY DR. L. HARRISON MATTHEWS, F.R.S.

PRESIDENT OF SECTION D

MAN has always been a predator on the fauna of the world, and in this address I propose to consider how man's activities have affected the world's fauna, to mention some of the population problems of the fauna that have been studied by zoologists, and to examine the conclusions that may be drawn from them.

Man has preyed upon the fauna of the world from the time that he first appeared as a distinct species. Until historic times, however, the human population was comparatively small or was growing at only a very slow rate; it may consequently be presumed to have reached a predator-prey relationship that was more or less stable. But for the last five or six thousand years the human population has been steadily increasing in one part of the world or another, and the former stable relationship with the fauna has been lost. The increase in man's numbers and the development of his technical skills has affected the fauna in more than one way, usually to its detriment. During the last hundred years the rapidly increasing rate of growth in both these factors has had repercussions on the fauna of the world that are nothing less than disastrous.

In man's primitive food-gathering stage he exploited for food and other useful products such members of the fauna as he could overpower, and now that he has invented mechanical aids to extend his comparatively weak physical strength he continues to exploit it with ever-increasing destructiveness, as seems inevitable when he reaps where he has not sown. Examples from the past are easily found: the former vast herds of seals, the arctic whales, the American bison, the passenger pigeon, the North Sea fisheries. These show how populations have been depleted, reduced to small remnants, or actually exterminated by the excessive exploitation made possible by technological advances. The populations of animals were so large that at first they appeared to be inexhaustible, and it was not until they had been reduced below the danger point that the despoilers realised what they had done. The easy gathering of rich profits was irresistible where faunas were unprotected and the harvest was free for all.

Direct destruction of particular species, however, has not been the main result of the pressure of an expanding human population: the destruction of the environment to which the fauna has become adapted during the course of evolution has been far more important. This destruction started long ago, presumably with the beginning of agriculture, when natural vegetation was cleared to make way for cultivated crops. Some of the deserts of central Asia, where the remains of cities, gardens and forests are buried under the shifting sands, may have been produced partly by human destruction of the vegetation, though it is possible that climatic change may have contributed to the desiccation. There is, however, no doubt that much of the desert of north Africa is man-made, just as are the modern dust-bowls of America, and the native fauna has disappeared with the flora. Even an alteration to the environment which results in a flourishing countryside for the farmer may none the less be a complete destruction of the environment as far as much of the fauna is concerned; human settlement of land and the development of agriculture are incompatible with the preservation of most of the larger animals. The great herds of ungulates of many species, and their accompanying predators, that once

[1] Address delivered to Section D (Zoology) on Thursday, September 3, 1959, at the York Meeting of the British Association.

freely roamed over many thousand square miles of South Africa have vanished, and a similar fate is rapidly overtaking the animals of East and Central Africa. When man competes with the fauna for possession of the environment the fauna has to go.

The larger animals have long been banished from closely settled countries such as most of Europe, yet there are some surprising exceptions in animals that can adapt themselves to an environment that is almost entirely artificial. Even in England there are considerable numbers of wild or feral deer at large in practically every county, although they are rarely seen and most people are unaware of their presence. Among the predators the fox is perhaps commoner than it would be were it not preserved for hunting, but the badger is numerous in many populous parts of the country where it is traditionally regarded as an enemy to the poultry-yard. On the other hand these creatures are not so powerful or destructive as the bear, wolf, or wild boar which have long been exterminated and whose re-introduction would be unlikely to be regarded favourably by public opinion.

Human settlement of any land produces a modification of the fauna, and this usually results in the extermination of the larger species and the re-arrangement of the smaller ones so that some form of co-existence is achieved. Those species that survive often become pests whose numbers are barely kept in check by continuous efforts at control. It is noticeable that many of the species that find the modified environment a favourable one were not originally native to the lands they plague, but have been introduced accidentally or deliberately by man, and have become unwanted commensals.

Throughout the world the pressure of human populations competing with the fauna for the environment is upsetting the established balance, and threatening at least the larger species of animals with extermination; indeed, some zoologists fear that by the end of the century many of them will be extinct. They deplore that so little detailed biological study has been made on them up to the present, and urge that intensive investigations should be started at once before it is too late.

The museums of the world need much larger collections of material than they possess at present, and it is greatly to be hoped that they will procure this material by taking advantage of the operations designed to exterminate animal populations in many parts of Africa in carrying out policies to control the tsetse fly. Zoological gardens and parks could help to save species from extermination by establishing breeding populations in captivity. An outstanding example of what may be achieved is the preservation of the Père David's deer, which is extinct as a wild animal, by the Zoological Society of London. In collaboration with the late Duke of Bedford the Society has distributed specimens of this species to zoological gardens throughout the world in order to promote its chances of survival; it has also repatriated the animal to its native land where it is now established so that for the first time in fifty years there are again *Elaphurus davidi* bred and born in China. Efforts might have been made to preserve the quagga in captivity, if the rapid decline of its numbers in South Africa had been realised in time—but for an unfortunate accident through which a quagga stallion was destroyed when it broke a leg in the London Zoo in 1864 the species might be with us still. Apart, however, from the work of museums and zoos, the biology and ecology of much of the world's fauna still awaits study—a study that must be made soon or not at all.

During the present century, and particularly during the last twenty-five years, those who have for long been concerned at the threat to the continued existence of much of the world's fauna have obtained some support from public opinion in their efforts to preserve it from destruction. Public opinion, however, is often sentimental and illogical, and requires many years of education before it can begin to understand the problems involved, or the lessons to be learned from them. Legislation now prohibits the killing of many rare species, and sometimes limits

the killing of the more plentiful ones; it also provides sanctuaries in the form of reserves and national parks where killing is forbidden, poachers are suppressed, and disturbance of the animals is prevented as far as possible by the watchers that staff them. In some reserves artificial water supplies are provided, but nearly everywhere the position is complicated by the rights of the native human inhabitants who are excluded and whose hunting or grazing rights are curtailed in their traditional home territories.

Of all reasons given for the conservation of animals other than those of commercial importance, the aesthetic one, that it gives pleasure to human beings to see living wild animals, is perhaps the most attractive. We are also told that it is our duty to posterity to preserve wild animals, but posterity may not be interested; is one person in a million at present distressed because the dodo, the quagga, the blue buck, and many other creatures are extinct, or does anyone regret that bears and wolves were long ago exterminated in this country? Some people think that animals have an inherent right to an undisturbed existence and, although they do not extend their tolerance to fleas, cockroaches or trypanosomes, would give the rights of animals preference over those of man.

Elton has recently emphasised the importance of conserving sufficient areas of complex ecological environment interspersed among the simplified artificial environment made by the farmer. In pest control and the prevention of outbreaks of single destructive species the complex environment provides a reservoir of natural enemies of the species harmful to agriculture. The conservation of variety both of habitat and fauna are essential to good land management which, as Elton also points out, will sooner or later have to be undertaken everywhere because human encroachment on formerly undeveloped territory is such that the ecosystems of the world will have to be scientifically controlled. Conservation will not be a negative process of preserving the *status quo*, but a positive one of managing world ecology to man's advantage both material and cultural. Conservation must be made to pay; it cannot succeed on a large scale if it does not, and unless it succeeds man will destroy his own environment.

In Great Britain the Nature Conservancy has started a large programme of ecological research the results of which will, I have no doubt, be not only of great academic interest but also of great practical importance. The nature of such work, however, is such that results are not obtained quickly and some years are bound to pass before anything more than a general view of the direction conservation should take can be apparent. In other parts of the world, except the U.S.A., no such co-ordinated researches are taking place, although many isolated projects deserving all support and encouragement are in progress. Africa is the continent where the rapid destruction of the spectacular fauna of large animals attracts most attention at present, but in speaking more of Africa than of other parts of the world I do not ignore the work that is now being done to preserve rare and interesting animals in sanctuaries in many parts of Asia and elsewhere.

National Parks are delightful places for tourists and sightseers, but they have little chance of being preserved permanently in the face of a demand for land for human settlement. The denial to settlement of large areas that are coveted for food production is not acceptable to local inhabitants who pay taxes that help to keep reserves sterile of agricultural or pastoral production. It appears to me that, if conservation is desirable, the only way to make it successful in the long run is to make it pay commercially, not just by collecting fees from tourists, but by making the land productive. Under proper management it should be possible to harvest a profitable crop of animal protein annually from the game to meet the growing demand for food, and in many places this is undoubtedly the best use to which the land can be put. Once it can be shown that conservation is commercially profitable those who desire conservation for other reasons are more likely to have their wishes

fulfilled; if it is not profitable conservation will be pushed aside whenever political pressure for land development becomes strong enough. No attempt to put the clock back for sentimental reasons can prevail against it.

One of the greatest obstacles to the scientific conservation of the fauna in Africa is the short-sighted attitude often adopted by local authorities. As land is taken into cultivation the animals which are pushed back into the ever-diminishing territory available to them may break back and devour the farmer's crops. He appeals to his representative in the Government who brings pressure to bear on the local game department to shoot out the destructive animals in his neighbourhood. It is of course a question of the farmer's living, but the extermination is done without any consideration of the fact that other countries have made so huge an overproduction of cereals that they have immense stocks on hand which they cannot sell. Similarly the animals over large areas of territory are blotted out in an attempt to exterminate the fly vector of trypanosomiasis so that European breeds of cattle can be introduced into country which is not really suitable for them. The improvement of native breeds and the use of new protective drugs may perhaps make such policies unnecessary in the future. It has always surprised me that more effort has not been devoted to the improvement of native cattle, in view of the wonderful improvements made in British cattle during the last two hundred years—our basic stock can have been little better than African scrub cattle of today. Conservation can make little progress in the face of a parochial administrative outlook where jealousies between departments, and between neighbouring territories, lead to lack of co-operation and conflicting policies. The rise of nationalism throughout the world makes conservation all the more difficult, for the conservation of the fauna is basically a world-wide problem; countries with interesting faunas should agree not to destroy them in attempting to develop lands that are ill adapted to human settlement and agriculture. But the difficulty of securing agreement on so comparatively simple a matter as the International Whaling Commission gives little encouragement to hopes for any larger measures of international conservation. The next five or ten years are the critical ones for the African fauna, and if inter-territorial agreement is not reached and put into practice within that period the larger at least of the African animals are doomed to speedy extermination.

A new conception of the function of conservation has recently been spreading among biologists. Conservation of the fauna is not preserving big game so that people may kill it for pleasure; nor preserving animals, beautiful as they may be, for tourists to admire; nor yet preserving them for study by biologists, however desirable the search for truth may be as an end in itself. Conservation is essentially a way of land management and development. It is a way that is not yet understood by the politicians and administrators. The official attitude seems to have made little advance beyond the stage of seeing the fauna as something to be got rid of, or else to be kept fenced off in reserves where it can do no harm. Development, to this point of view, means turning what is seen as unproductive bush into cultivation or grazing. But is the bush potentially unproductive? It is important for people to realise that the fauna is one of the most important natural resources in many parts of the world. During thousands of years of evolution the fauna has become adapted to the local ecological conditions and may well be by far the most efficient means of producing energy—food and other products useful to man—from the land to which it is so well adapted. If it is destroyed quick profits may be made for a few years until the land is exhausted, and then we are left with a desert. Darling points out that to exchange the wide spectrum of some thirty African ungulates living in delicate adjustment to the poor and tender habitat, for the narrowed spectrum of three ungulates exotic to Africa—cattle, sheep, and goats—is to throw away a bountiful natural resource and the most efficient system for the conversion of vegetation. Everyone agrees that the proper way to develop an unexploited territory

is to develop its natural resources, but we are so obsessed with the tradition of pastoralism and agriculture that few have yet grasped the fact that the fauna, too, is one of the natural resources awaiting development.

Biologists know how complicated the interrelations of an ecosystem may be, and that destroying one factor in the structure may ruin the whole system, but this is an idea that is quite unknown to those who administer the undeveloped regions of the world. Controlled exploitation of the fauna could probably be made to yield more useful produce more efficiently and more cheaply than any other method of development, but until this fact is widely appreciated we shall continue to devastate the land. I am sure that the greatest service that zoologists can do to the laymen is to get him to revise his views on the place of the fauna in the ecosystem, which includes man himself, so that he conserves the fauna to its and his own advantage. This I believe is the key to the whole problem of man's relation to the fauna of the world—its conservation is not a matter of sentiment or even of a duty for preserving it for posterity, but merely one of hard economic facts, a question of the best way of managing land use.

Much patient research is necessary before conserved areas can be brought to a satisfactory level of production; at present the knowledge for achieving this result in most parts of the world does not yet exist. Only in the United States has such work been advanced far enough to be of practical value; the art of game-management is growing into a science through the work of the U.S. Fish and Wildlife Service, and the U.S. Soil Conservation Service. In Africa, Asia and elsewhere, however, very little such work has been done, and most of the conservation so far attempted has been empirical and has consisted of no more than prohibiting the killing of certain species, or of all species in limited areas. In many of the African territories the Game Departments are regarded as the least important parts of the administration and are starved of funds and staff. Few of them include any trained zoologists, and though many of the personnel are men of great practical experience they have neither the knowledge of zoology nor the training in ecology necessary for laying the foundations of the scientific management of conservation. The number of Government biologists engaged on research on problems of the fauna in the whole of the Commonwealth territories of Africa is less than a dozen. The type of basic work required is shown by the brilliant ecological survey of the Serengeti area recently made by Professor Pearsall, and the survey of population numbers made on the same plains by Michael Grzimek, and now ended by his tragic death.

If the fauna of Africa is to be preserved a very large effort of research must first be undertaken, nothing less than a Biological Survey of Africa is required in which plant and animal ecologists, soil experts, systematists and ethologists, collaborate in obtaining the facts upon which alone successful conservation can be based. A modest beginning has been made by those already in the field and by those who have made visits for limited periods, but something much larger with central co-ordination is needed. I hope I may be pardoned for feeling some satisfaction that over 20 years ago I was one of the first zoologists to visit Africa to make a detailed study of a single species of animal, one of the commonest and least esteemed, the Spotted Hyaena.

The biological surveys carried out by the Belgians in the Congo and the present researches of the Nature Conservancy in Britain are examples of what might be undertaken.

Turning now to the conservation of animals specifically for commercial purposes, the history of the sealing and whaling industries shows what may be done. Enormous herds of fur seals and elephant seals lived undisturbed on the shores of the sub-antarctic islands until the end of the eighteenth century. In the early years of the nineteenth century a few English and many American sealing captains took their

ships into those hitherto unexplored regions and found rich profits awaiting them. They killed such immense numbers of fur seals for their pelts that in about a quarter of a century the animals had been almost exterminated and so few were left that it no longer paid to hunt them. The sealers then turned their attention to the elephant seals from whose blubber an oil as valuable as whale oil could be extracted, and it was not long before the population of the elephant seal too had been reduced to a remnant. Elephant sealing was then combined with whaling: whale ships used to land shore parties on Kerguelen, Heard Island, South Georgia and other sub-antarctic islands, and leave them for many months to collect a meagre harvest of seal oil while the ship cruised in warmer latitudes for sperm whales and black-fish. It was a hard life without amenities, and the sealing crews lived like savages. Early in the present century even this miserable trade came to an end for lack of prey. Fur and elephant seals seemed to be on the verge of extinction. For many years the remnants were left almost unmolested, and when the Falkland Islands assumed responsibility for the administration of the antarctic Dependencies in 1908 the numbers of elephant seal on South Georgia had made a remarkable recovery. One of the whaling companies was granted a licence to exploit the population commercially, but conditions were imposed that were intended to preserve the numbers. They were highly successful, largely owing to the fact that elephant seals, like nearly all seals, are polygamous. The sexes are born in approximately equal numbers, but because each adult bull collects a harem of two dozen or more cows a large number of unsatisfied bulls remain in the breeding colonies. The sealing regulations allowed bulls only to be taken and required that at least 10 per cent of the bulls should be left at the annual killing. This policy has been so successful that not only have the numbers of the animals been maintained but they have increased greatly during the last forty years, and the species is fast building up populations on other islands of the dependencies. A similar policy, based on what one may term a lucky accident in the biology of seals, has been applied with equal success to the fur seals of the Pribilof Islands in the North Pacific and elsewhere. The seal fisheries that are now properly managed are a striking example of successful conservation introduced not from any sentimental or humanitarian motives but solely for commercial reasons.

The history of the whaling industry is not so satisfactory. The large antarctic population of Rorquals was left completely untouched by the whaling industry until several years after the beginning of the twentieth century, although modern whaling methods had reached a high level of development since the invention of the harpoon cannon between 1860 and 1870. As soon as a pioneer venture had shown the great profits that awaited gathering in the Antarctic many whaling concerns started work in the south, and within a few years it was evident that the whale population was being over-exploited. The government of the Falkland Islands imposed empirical regulations to protect the industry, but realised that more knowledge of the biology of whales was needed before sound management could be achieved. The *Discovery* Investigations were therefore launched to make a wide study of the biology of whales and their environment, a very large task in oceanography which continues today, more than a quarter of a century after the R.R.S. *Discovery* set sail in 1925.

One of the first facts found by the Investigations was that whales breed more often and reach adult stature much more quickly than was believed; it had been assumed that because whales are so large their growth was slow, they lived to a great age, and their reproductive rate was slow. The Investigations showed that even the largest species breed every other year, the young are weaned at six months, and are sexually mature at three or four years of age and probably reach physical maturity at under ten; the age of the oldest whale examined was estimated at only about thirty years. The development of a Blue whale from conception to birth

is the most spectacular example of growth in the animal kingdom—the fertilised ovum, smaller than a pin's head, grows in twelve months to a young whale twenty-five feet long and weighing two or three tons. Within a few years much information had been gathered about the biology of whales, their migrations, their food, and their environment, upon which sound regulations for the scientific management of the whale population could be based.

By the time this was accomplished, however, a new factor arose. Until 1925 whaling was carried on from shore bases which required official licences and were easily subject to control. But in that year the first pelagic whaling expedition was sent out, based upon a floating factory that could work anywhere on the high seas where whales were abundant. It was consequently independent of the regulations covering whaling based on land stations within territorial jurisdiction. The governments concerned were, however, sufficiently prudent to realise that a free-for-all could only end in the ruin of the industry, and rules were laid down by international agreement to restrict whaling to certain times and places, and to take only whales of adult size. The regulations were intended to ensure that an annual crop could be gathered of such a size as to conserve the total population by killing fewer whales than were born annually. Unfortunately, although the biological information was available, political and other vested interests were strong enough to ensure that the regulations fell short of providing the necessary full protection. The numbers of whales or the age composition of the catch, especially of the large and more economically desirable species, has continued to fall. The Blue whale at least appears to be well on the way to extermination. Nevertheless the international agreements have undoubtedly helped to reduce the rate of destruction of the stock of whales, but now international rivalry threatens to remove even these inadequate regulations. In 1959 the nations concerned cannot agree on the proportion of the world catch each is to take, and several of them threaten to withdraw from the agreement. The zoologists have provided the information: if governments will not make use of it for scientific conservation when pressed to ignore it by commercial and political interests, the outlook for the industry is even bleaker than that for the whales because it will perish long before the last whale has been killed.

The sea-fishing industries of the world, like sealing and whaling, are predatory, but their conservation is very much more difficult. The closing of former public fishing grounds by the arbitrary extension of territorial waters appears to be the result of a wish to abolish competition between the fishermen of different nations rather than of one primarily to conserve the stocks of fish. On the other hand, it was the depletion of the fishing grounds of the North Sea through overfishing that gave rise to fisheries research and the foundation of bodies such as the International Council for the Exploration of the Sea and many national fisheries research institutions. During the last eighty years great advances have been made in our knowledge of the biology of many marine food fishes, and of the ecology of the sea. But although this knowledge has been applied to the framing of restrictive regulations in an attempt at conservation, it is doubtful whether all the effort and wealth expended in research have caused one more fish to swim in the sea than before, though it may have helped in retarding the process of depletion. New fishing grounds have been discovered, and new and more efficient methods of fishing have been introduced by the enterprise of the industry itself; yet although overall landings have increased from time to time, overfishing has continued. It is unlikely that the fertilising action of all the sewage from a large part of Europe poured into the North Sea has increased the potential production of the fishing grounds. Only recently has the suggestion been made that nuclear power might be used to promote an artificial oceanic circulation whereby deep water, with its nutrient salts, might be drawn up to the surface layers to stimulate the growth of plankton and, by strengthening the food chain at its first link, increase the productivity of the sea.

The problems of conservation in the sea are, however, in one respect less difficult than those of conserving the land fauna because it is very much more difficult for man to destroy the environment, or even to modify it on anything but a small and local scale. The greatest menace at present appears to be the dumping of atomic waste in the ocean depths, for no container can be everlasting, and sooner or later the radioactive material will be released. The pollution of the surface waters with oil is inexcusable now that methods of avoiding it are known, and those too mean or too lazy to employ them should be restrained from continuing to inflict damage on their neighbours. Some progress has fortunately been made in this direction during 1959, but clean oceans are still far over the horizon.

In conservation of the land fauna the basic principle is to conserve the environment, and conservation of the environment includes the careful control of the numbers of animals for which it is preserved lest they themselves destroy it. This point is well illustrated by the investigations of Leopold and Darling on the introduced reindeer population of Alaska. The reindeer were introduced to take the place of the native population of caribou which had been greatly reduced by excessive hunting and the destruction of the winter range by fire. They were carefully herded and protected from human and animal predators, and consequently increased greatly. But the winter food of the deer is a very slow-growing lichen which was seriously overgrazed by the rapidly expanding population so that the winter pastures were nearly destroyed. The destruction was increased by accidental fires, and the damage done was so great that much of the pasture will need fifty years or more to regenerate. As a consequence thousands of reindeer died; there were some 3,000 deer in the territory by 1900, a few years after the first introduction, the peak in numbers was reached in 1932 when they totalled 650,000 and now there remain only about 25,000.

A similar example is provided by the hippopotamus in the Elizabeth National Park in Uganda. As a result of complete protection for some years the hippopotamus increased to excessive numbers and increasingly overgrazed the herbage in the neighbourhood of the river so that land erosion began as a result of the loss of the cover of vegetation. When it appeared that a reduction in the numbers of the animals was urgent in order to preserve the environment an experimental operation of control was undertaken after much deliberation. It was undoubted that the hippopotami were destroying their habitat but some biologists have expressed the opinion that artificial control was unnecessary and argued that if the animals were left to themselves the numbers would finally decrease naturally either from starvation or from the occurrence of an epidemic disease. They believed that the habitat would then recover, and that a similar cycle of gradual increase followed by a catastrophic decrease might be repeated. This is an interesting opinion because such a violent reduction in numbers is known to have occurred when great numbers of hippos died during a drought in the Lorian Swamp in northern Kenya in 1928. Others regard this as an academic view which ignores the practical necessity of limiting the excessive swing of the pendulum that may be habitat-destroying at both ends.

Little scientific investigation has been made on the population dynamics of the larger mammals with the exception of certain species of deer in Europe and North America. But much careful and painstaking study has been devoted to that of some of the smaller animals, work pioneered by Elton and his colleagues at the Bureau of Animal Populations in Oxford and extended by zoologists in many parts of the world. This branch of zoology is based on the often observed fact that the numbers of small mammals, particularly rodents, in certain parts of the world habitually increase enormously at approximately regular intervals so that 'plagues of voles' occur in Europe, or of jack-rabbits in North America. The vole cycle occupies three or four years, the jack-rabbit cycle about ten, and the numbers of the predators show similar cycles with a time lag of about a year.

At the beginning of a cycle of increase the animals are few and food is plentiful so that there is nothing to prevent a rapid build-up of numbers. At the peak of numbers the habitat may show some signs of the population pressure—in a vole plague the pasture is described as presenting an untidy, over-grazed, 'moth-eaten' appearance. Nevertheless food is still abundant when the catastrophic reduction, or the 'crash', arrives. Years of hard work had been devoted to finding the cause of the crash, and many lines of research had been carefully followed, without arriving at a definite conclusion, until Selye put forward his conception of the stress syndrome, which appears to account for the majority of the phenomena characteristic of a crash following a cyclic increase in numbers of a population of animals.

The stress syndrome is the result of a number of causes acting and interacting at the same time, but essentially it is the product of psychological stress. All animals, even gregarious ones, need a certain minimum area as their private territory. Hediger has beautifully illustrated this with his photograph of a flock of flamingos resting in a line spaced at regular intervals; although these birds are gregarious each needs a radius of a foot or two of privacy for comfort. Even the so-called 'contact animals', which like to cuddle together when at rest, need a particular radius of privacy when foraging and feeding.

When a population of small mammals such as voles or jack-rabbits reaches its peak in numbers the food supply may be adequate, but the overcrowding denies each animal an undisturbed enjoyment of its necessary private territory. As a consequence there is a continual bickering as the animals try to keep intruders at the minimum distance and as the females repel the excessive attentions of the males. A state of acute psychological tension is produced throughout the population which acts in a way not yet properly understood upon the pituitary. The dysfunction of the pituitary appears to result in an over-production of the adreno-cortical stimulating hormone (ACTH) and this in turn over-stimulates the adrenal so that the production of corticoid hormones is at first stimulated and then completely exhausted, and it is the breakdown of adrenal function that causes the rapid death of the animals and the sudden dramatic decrease of the population. Thereafter the build-up of the next cycle starts from the survivors. This account is, of course, much abbreviated and simplified, but although the detailed story is very complex, the overall picture is broadly correct.

Here I should like to make a digression into applied biology and to turn from examining what man has done to the world's fauna to a consideration of what we may be excused for thinking to be the most important member of that fauna, man himself. The basic root from which stem all the problems of the destruction and conservation of fauna is the growth of the human population so that man is increasingly competing for territory with the rest of the fauna. Zoologists well know that we are part of biology, but probably the largest part of humanity erroneously consider themselves as something apart and exempt from the processes that regulate the lives of the lower animals. The most serious problem at present facing the human race and the rest of the fauna is the frightening rate of increase of the human population, especially in the so-called underdeveloped parts of the world. There are many causes for the increase, all of them produced by man himself, such as the astonishing advances made in public health during the last two decades. But all these modern advances have not emancipated human populations from the old Malthusian dictum that however much food production is increased the numbers of the population increase faster and overtake it. The United States Population Reference Bureau has stated that in 1958 the population of China increased by about fifteen million, of India by six million, of Russia by over three and a half million, and of U.S.A. by over two and a half million. The total world population increased by forty-seven millions, and if the present rate of increase continues the

total will be doubled by the end of the present century, only about forty years from now. It has been estimated that if the present rate were to hold there would be one person on every square yard of the earth's surface in a little more than a thousand years.

Such rates of increase will not, of course, occur, but should the alteration be left to chance, or rather to the unavoidable consequences of inaction, or should it be deliberately controlled? Inaction will certainly produce very uncomfortable results, but deliberate control might achieve the necessary reduction without widespread suffering and with some measure of comfort to all. Last year the U.S. department of Agriculture stated that total food production in the major countries of the free world rose by about 28 per cent between 1939 and 1958 but population increased nearly as much so that the amount of produce rose only by one or two per cent per head. In the Communist countries population had grown faster than production which, although increased absolutely, had declined by nearly 7 per cent per head. Some people believe, in my opinion erroneously, that science will be able to increase production without limit so that sufficient food can be provided for all, no matter how high the population climbs. Past and present experience give no grounds for such complacency; there would be no room to produce food, or indeed anything else, far less to conserve the fauna, if there were one person on every square yard.

It is, however, well known that the growth of human populations tends to become slower and to reach a stable level with the increase of standards of living, and some people hope that this tendency will automatically solve the problem. It is possible that it may; but will a stable level be reached with numbers sufficiently low to make life worth living? Nothing is worse than overcrowding; one has only to spend a holiday in Eire, whose total population is only about four million, to realise how much pleasanter life is in a country less crowded than Great Britain, even if the standards of living are equivalent to those of this country fifty years ago. Overcrowding indeed may be a controlling factor not for material but for psychological reasons.

If we compare the present build-up of the human world population with the cyclic build-up of populations of small mammals it is tempting to draw the conclusion that our population is nearing a peak and that a catastrophic crash is imminent. Richter has recently pointed out that, although many of our modern amenities are directed towards reducing stress, there is in the more advanced countries an enormous increase in diseases that respond symptomatically to the administration of cortisone or adrenocorticotropic hormone. Can it be that the pace of modern civilisation is producing a mass stress syndrome that will bring a catastrophic crash of the populations of America and Europe? It is possible, especially in view of the essentially unsatisfying, aimless and materialistic outlook on life that is so widespread. On the other hand, man is one of the species that seems able to survive serious overcrowding.

There are two other possible ways of decelerating the disastrous rate of growth in the population. The first has already been perfected. Population pressure on the environment leads to the development of unoccupied territories, but before saturation point has been reached envious eyes are turned upon neighbours who are thought to be more prosperous. In the past, wars of conquest have been fought partly for this reason, and partly for reasons of national prestige; man unfortunately is innately aggressive, and the greater his inferiority complex as an individual or nation the greater his urge is to assert himself. Wars of the future might, however, be waged to secure standing room, and man has now invented the cheapest and easiest way for destroying himself that could be imagined. It is said that six, or at most nine, nuclear bombs or rockets would effectively annihilate London. There must be ample supplies of weapons in the stockpile to eliminate in a few days a

third of the world population, about a thousand million. Provided that operation did not contaminate too much of the world with radioactivity a useful amount of elbow room would be left for the survivors. The subject of radio-active contamination is however little known, and in spite of assurances, it is possible that the seeds of the needed reduction have already been sown and will bear fruit in the next hundred years. Do not misunderstand me or think that I regard such a possibility with anything but horror, but I think it is a real danger and that we should be fully aware of it lest it become a reality.

The second method has yet to be perfected, though had a fraction of the funds expended upon the first been available for the necessary research it would probably long ago have been available in unlimited quantity. The obvious requirement is a method of inhibiting fertility in the male or female or both for a definite and limited period. Much research has been devoted to this subject, but although success is close, Aldous Huxley's pill of the Brave New World has not yet been produced. I have no doubt that this problem will be solved and the more effort that is applied to it the sooner humanity will be able to enjoy its advantages. Such a substance should be available to all at low or, preferably no, cost, after a survey had determined the best population density for each part of the world. We might then find governments imposing a heavy tax on the parents of more than two or three children, and abandoning the folly of subsidising irresponsible parents for laying further burdens upon their neighbours in an already overpopulated country. There will, of course, be opposition from many quarters. Russia has announced to the Economic Commission for Asia and the Far East that she is opposed to any limitation of the Asiatic population; governments still cling to the old idea that large populations of cannon fodder are desirable. Many religious bodies too strongly disapprove, although they condone war; it is surprising that there are bishops willing to bless battleships, bomber aeroplanes, or troops before battle, but who condemn birth control.[1] It is difficult to believe that it is right to inflict indescribable suffering upon people, but that it is wrong to avoid procreating them to endure such horrors.

The lesson for mankind to learn from biology, and particularly from the study of animal populations, is that an uncontrolled increase in numbers inevitably builds up to a crash. The human population is rapidly increasing; how then shall we avoid an extremely unpleasant crash? There are three choices; the first to do nothing, and wait for the stress syndrome, or some new virus like that of myxomatosis or influenza to do its work; the second, to leave the destruction of civilisation to the trigger-happy politician with the largest stock of nuclear weapons; the third, to decide what is the optimum population and to ensure, by completely innocuous methods, that it is not exceeded. History, unfortunately, gives no encouragement to the hope that the desirable alternative will be chosen.

To return from a special case to a general consideration of the fauna of the world, it is quite clear that everywhere the larger and more conspicuous members of the fauna are threatened with early extermination and the praiseworthy efforts at their conservation have barely scratched the surface of the problem.

If it is agreed that the preservation of the world's fauna is desirable, conservation must be planned on a world-wide scale and not piecemeal. First it is necessary to decide what parts of the world are to be developed for human occupation, and only then will it be possible to decide what parts of the remainder are suitable for conserving the fauna, if the human population agrees to limit itself and refrain from competing with the animals for territory. A comprehensive research should then investigate every aspect of conservation, starting with a thorough ecological examination of the areas affected. The results, which would include information on the carrying capacity of the land and the conversion efficiency of larger members

[1] I do not specifically refer to the Church of England.

of the fauna, would provide the basis for scientific conservation and, the most important point, for making it economically profitable. Time is short: some of those who have most closely studied the problems of conserving the fauna of the world consider that in Africa the next five years will be decisive. If things are allowed to drift during that time it will be too late to save the fauna, which will be exterminated for ever.

At this point I might be expected to urge the British Association for the Advancement of Science to set up a committee to study conservation and to bring pressure to bear in official quarters to put it into practice. But I refrain because a number of national and international bodies interested in conservation already exist; there has been too much talk and too little action. Within the last few years the prospects of doing something to conserve the fauna and flora of the world have somewhat improved with the stirring into activity of the International Union for the Conservation of Nature, the Conservation Foundation (U.S.A.), the suggested British Overseas Conservation Service, and similar organisations.

A few years ago a very modest plan, which had official support, for research on the ecology and general biology of the East African fauna expired shortly after its birth through lack of local interest and financial support—a tenth of the money spent on the unsuccessful ground-nuts scheme would have covered it many times over. I have, I regret to say, heard criticisms of the Americans for trespassing on British preserves in sending Fulbright Fellows to study special aspects of the African fauna; science is international and such an outlook is entirely out of keeping with its spirit. The British have been in occupation of many of the territories where conservation is most urgently needed for half a century, but they have done little even towards studying its preliminary problems. Indeed, their occupation has resulted in the destruction of the fauna on an immense scale. If therefore our neighbours, with all their resources of wealth and scientific man-power, are willing to undertake our neglected duties we should welcome their interest and do everything in our power to co-operate with them. If their, and our, researches can convince authority that conservation will pay, both directly by producing an economically valuable crop, and consequently more contented populations of people—Darling pithily remarks that starch and sedition go together—and indirectly by maintaining a wide variety of ecosystems, there is some hope for the continued existence of the fauna.

A start has been made; only ten days ago I was glad to read a report that in the Tana district of Kenya, an area until recently infested by destructive ivory poachers, a scheme has been started under which the Waliangulu hunters are to crop the game under the supervision of the rangers, so that the annual take shall not exceed the regenerative capacity of the herds of elephants. Some 200 elephants will be fully used annually, where the poachers formerly killed over 1000, and left the meat to rot. The Nuffield Foundation has made a grant of £10,000 towards the scheme, and the important point, as the report emphasises, is that a game department and a charitable foundation have at last faced the simple fact that meat-eating Africans need meat. This experiment may have very far-reaching results. I hope it will.

The future is, however, always uncertain whatever our hopes. I would therefore urge all zoologists who have the opportunity of studying any aspect of the biology of the larger animals to seize it without hesitation, and, concluding rather cynically, I would commend all natural history museums and zoological gardens to preserve what they can before it is too late.

TRENDS IN URBAN EXPANSION[1]

ADDRESS BY PROFESSOR K. C. EDWARDS

PRESIDENT OF SECTION E

THE ancient city of York, as we are all aware, was the birthplace of the British Association. At the first meeting in 1831, among the committees set up to consider particular scientific problems, was one for Geology and Geography. At the next meeting, reporting on behalf of this committee, the Rev. W. D. Conybeare, an eminent geologist, quoted an interesting remark of Alexander von Humboldt concerning his travels in the New World: 'While on entering a new hemisphere we change all familiar and accustomed objects—while in the plains around we survey entirely new forms of vegetable and animal being, and in the heavens above our heads we gaze on new constellations, in the rocks under our feet, alone, we recognise our old acquaintances.' Now, if von Humboldt, the centenary of whose death we commemorate this year, could make a journey from Europe today to any of the other inhabited continents, the item which he would most easily recognise as an old acquaintance would be a feature of the cultural rather than the physical landscape, namely the large city. For during the past century large cities have not only become manifestly more widespread in distribution but are now becoming increasingly more uniform in external appearance. The latter characteristic arises from a general use of similar forms of urban equipment such as steel-frame buildings, illuminated signs, up-to-date street lighting and the paraphernalia of transport. These are the products of recent technical advance, mostly of Western origin, the diffusion of which is speedily effected by present-day methods of communication. Thus cities the world over, West European, American and Oriental, tend increasingly to merge their identities' (1).

Other changes of far greater significance, however, have latterly affected the development of towns and cities. Not since 1937 when my distinguished predecessor the late Prof. C. B. Fawcett delivered his address on 'The Changing Distribution of Population'' (2) has a president of this section ventured to consider the trend of urban development. In the intervening period a substantial advance has been made in the pursuit of Urban Geography as a distinct field of study. In Britain this progress owes much to two of Fawcett's pupils, Prof. R. E. Dickinson and Prof. A. E. Smailes, who have played a leading part in formulating the subject, in revealing its depth and in giving form and order to its content. With theirs and many other notable contributions, geographers are now in a much stronger position to deal with urban problems than was the case a quarter of a century ago.

HISTORICAL PROGRESS OF THE TOWN

In presenting the facts of recent urban expansion, even at the risk of traversing well-known ground, it is convenient at the outset to establish a broad historical perspective. The earliest appearance of the town in rudimentary form dates from Neolithic times in the East. Its emergence as a distinct unit of settlement, dependent upon the food surplus raised by neighbouring agricultural communities, initiated a new phase in the organisation of human society. This fundamental advance has been made familiar to us in the writings of Prof. V. Gordon Childe as the Urban Revolution' (3). About 5,000 years ago cities in the great river lands of the Indus, Tigris-Euphrates and Nile attained considerable size. Archaeological evidence

[1] Address delivered to Section E (Geography) on September 4, 1959, at the York Meeting of the British Association.

relating to a somewhat later period indicates that those of Mesopotamia such as Ur, Lagash and Assur had populations of the order of 20,000. Still later, leading cities like Nineveh and Babylon in the last millenium B.C. became outstanding, recent estimates placing their population at about 80,000 (4). At their zenith these surpassed all other cities, as did London and Paris in the West before the Industrial Revolution.

With the early development of cities in China we need not be concerned. As indigenous centres these cities long remained remote from contact with other regions. Over the rest of the Old World, on the other hand, the spread of the city was far-reaching, its occurrence always being dependent upon surplus agricultural production. The distribution of cities throughout Eurasia by A.D. 100 was limited northwards by climatic control over cultivation as Vaughan Cornish showed, although his notion of the 'isothermal frontier' was based on a doubtful use of mean annual temperatures (5). A more illuminating concept is that of Prof. H. J. Fleure in tracing the spread of the city, by progressive stages of cultural development, from the desert margins of the East along the Mediterranean shores into the cool temperate forest lands of Western Europe, advancing eastwards again beyond the Rhine after A.D. 1000, and ultimately, in the nineteenth and twentieth centuries, across the Urals into Siberia and the cool temperate Far East (6). This brief reference does less than justice to Fleure's argument, but it serves to remind us of the dynamic nature of urban progress. There was also of course the transference of the town in its European form to the Americas and other lands during the periods of overseas colonisation which extended its distribution mainly within temperate latitudes.

Industrial Urban Growth

With the modern industrial era came a major recrudescence of urban development. On account of its character and scale this is sometimes regarded as a Second Urban Revolution. In areas which possessed the natural resources and which either produced or acquired the new techniques for large-scale manufacturing, existing towns were transformed and entirely new aggregations brought into being. The age of steam-power produced *Coketown* many times over, first in the coalfields of Britain, then in France and Belgium, and afterwards in Pennsylvania and the Ruhr. Nor was there need for Dickens to coin the name, for in the English Midlands Coalville and Ironville were actual creations. The intensification of urban groupings became characteristic of all industrial areas. Towns of 100,000 inhabitants and over became commonplace, while smaller centres of 20,000 to 50,000 often developed in groups or clusters. Moreover, the correlative growth of international trade, assisted by railway and steamship, promoted an expansion of towns, especially ports and collecting-centres of raw materials, in parts of the world distant from the manufacturing regions.

Urban development associated with industrialism has continued to the present day, affecting an increasing number of countries. Recent decades, however, have witnessed a marked acceleration of the process, and the world is now experiencing an expansion of towns and cities on a scale hitherto unknown. Moreover, while industrialisation remains a primary factor, it has come to play a relatively less important part in the crowding of people into urban areas.

The Latest Phase of Urban Growth

Now just as urban expansion in the nineteenth century was accompanied by a sharp rise in world population, so the latest phase has coincided with an even greater increase. The recent acceleration of urban growth began after the First World War and became even more rapid after the Second. At the time of the First World War the earth's inhabitants numbered about 1,700 million; today there are

2,800 million. By 1980, if the present rate of increase is maintained, it will be 3,400 million. This means that within the normal life-span of persons born shortly before 1914, the world's population will have doubled. Since there can seldom be a direct connection between demographic trend and rate of urbanisation, we cannot predict the world's urban population for 1980, but there is evidence of its upward trend in almost all parts, and in some countries today town growth regularly exceeds the annual increase in total population. For example, in the U.S.S.R. the results of the latest census, the first for twenty years, show that between 1939 and 1959 the population within the present territory of the Union rose by 19 million, yet the urban population increased by 39 million (7). Present-day Japan, however, presents an instance of the likely effect upon urban expansion of a new demographic trend. The recent spectacular fall in the birth-rate from 34·3 in 1946 to 18·5 in 1956 has reduced Japan's birth-rate to a figure comparable with that of France and only a little above that of Britain (8). This abrupt reversal of the pre-war situation has been encouraged by legislation introduced in 1948 permitting birth-control measures. Since Japan's population is no longer one of high fertility the growth of her cities will henceforward depend chiefly on migration.

Unfortunately, owing to the lack of a common definition among different countries as to what constitutes an urban population, it is impossible to attempt a quantitative measurement of urban growth for the world as a whole. We can nevertheless obtain some idea of its scale over the past forty years by considering only the large towns, i.e. those of 100,000 inhabitants or more, since either census figures or reasonable estimates for towns of this size are available for nearly all countries for the periods 1910–13 and 1950–53, respectively (9). The results of such an analysis are summarised in Table I. This can only provide a crude indication of urban growth, because, apart from the doubtful reliability of census returns in backward countries, no allowance can be made for changes in municipal boundaries without detailed knowledge of every town.

TABLE I

	No. of towns of 100,000 *inhabitants or more*	*Size-groups (population in thousands)*				
		100–250	250–500	500–750	750–1,000	*Over* 1,000
1910–13	322	200	63	33	8	18
1950–53	1,071	611	299	67	32	62

The figures show that the number of large towns in the world more than trebled. Within the separate size-groups, those with a population of 100,000–250,000 also increased threefold, while those of 250,000–500,000 multiplied almost fivefold; and even those exceeding a million, the so-called millionaire cities, showed an increase of more than threefold. A marked upward trend in the mean size of the large town is also to be noted.

The most spectacular evidence of size-increase, however, is afforded by the advance of the millionaire cities. Their numbers as shown in Table I refer only to single administrative units of that size, but in the form of conurbations they are substantially more numerous. In fact the total increases every year. The growth and distribution of these great cities has been the subject of several studies made by geographers in recent years (10). Thus Dr. A. Lambert infers that as recently as 1955 there were about eighty, yet today the figure is nearer ninety, for in Asia

alone, Bangalore (Mysore State), Victoria (Hong Kong), Singapore and Pusan, the erstwhile refugee city, must now be included, while others such as Brussels, Munich, Prague, Turin, Baku and Kobe are on the threshold. These vast agglomerations, of which London and Paris were the only instances a century ago, are no longer exceptional. Some 200 million people now live in them and the day is not far off when they will shelter one-tenth of all mankind.

Ultimate Urban Aggregations

Yet the great conurbations, including mammoth cities like London, New York and Tokyo, are not the ultimate stage in the process of urban accretion. On the Atlantic seaboard of the U.S.A. the coalescence of coastal and Fall Line cities has led in

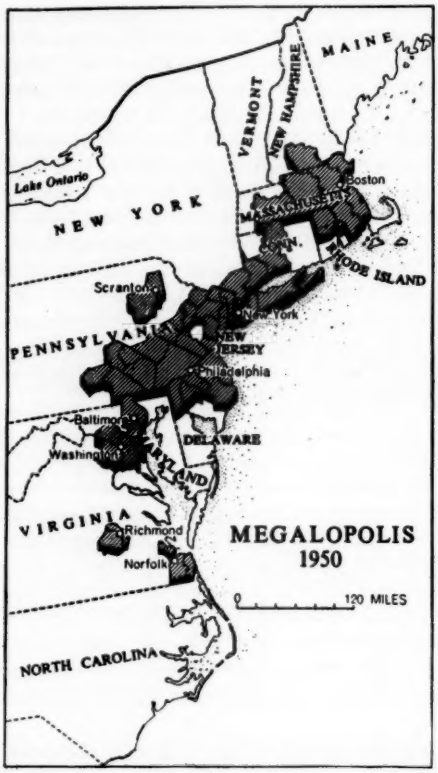


FIG. 1. Urbanisation of north eastern U.S.A. (J. Gottman). Reproduced from *Economic Geography* by permission.

recent years to the formation of a nearly continuous stretch of urban and suburban settlement extending for 400 miles from Boston to Washington and containing over 30 million people (Fig. 1). This immense concentration, which Gottman has termed *Megalopolis*, is at present without parallel, but is likely to be repeated elsewhere in North America (11). Similar continuous aggregations may eventually arise in Western Europe, as for example within the area lying between the Ruhr and the North Sea coasts of France, Belgium and the Netherlands. In England, as shown in Fig. 2, *Megalopolis* is taking shape in the Midlands and the North, based on a nineteenth-century urban pattern. This may ultimately take the

form of an ellipse enclosing part of the Southern Pennines, a portion of which, incidentally, is already sealed from further development by the creation of the Peak National Park. The existing urban units within this aggregation already contain a population of 13¼ millions. Current trends in industrial development and

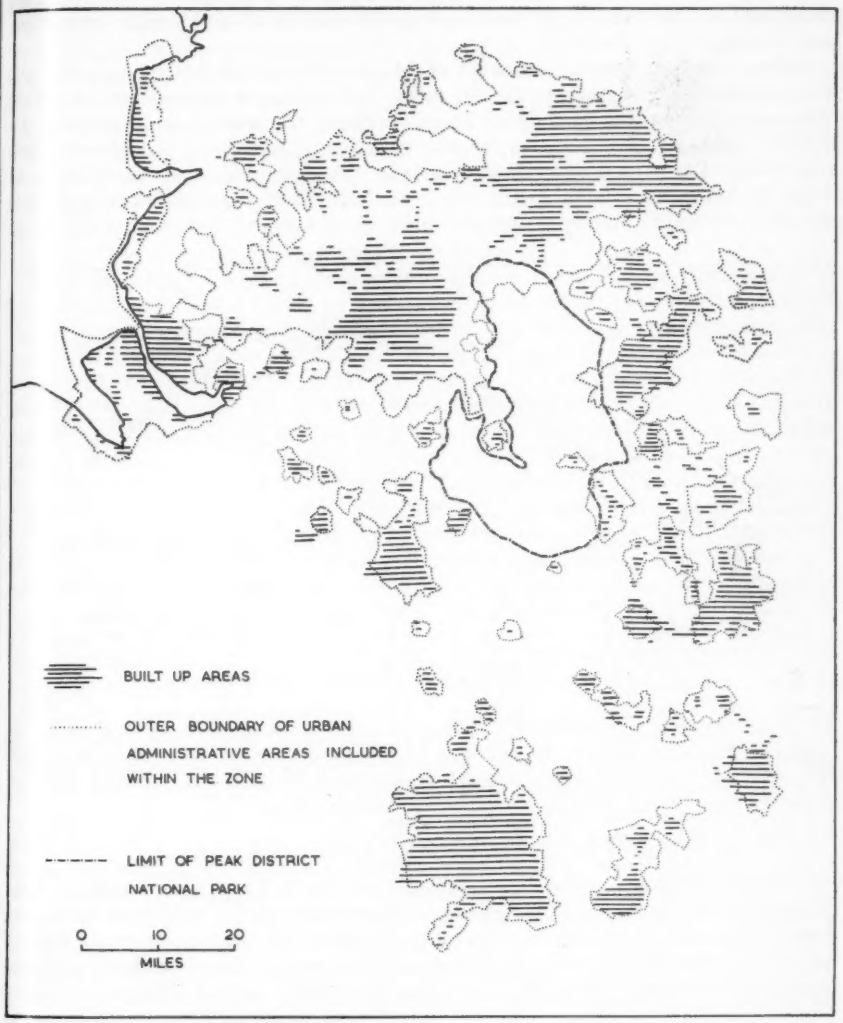

BUILT UP AREAS
OUTER BOUNDARY OF URBAN ADMINISTRATIVE AREAS INCLUDED WITHIN THE ZONE
LIMIT OF PEAK DISTRICT NATIONAL PARK
0 10 20
MILES

FIG. 2.

population movement favouring the south-east may, however, operate against the attainment of the ultimate stage. It is not impossible of course that in the distant future the spread of urban and suburban settlement from Greater London may itself reach the fringe of our potential *Megalopolis* along the axis of the Birmingham motorway (12). While speculation is not science, it is apposite to recall a prophetic essay by H. G. Wells on *The Probable Diffusion of Great Cities*, written in 1901 (13). Discussing the promotion of urban growth by improved methods of transport,

nearly all of which have since materialised, Wells wrote: 'It is not too much to say that the London citizen of the year 2,000 A.D. may have a choice of nearly all England and Wales south of Nottingham and east of Exeter as his suburb, and that the vast stretch of country from Washington to Albany will be all of it "available" to the active citizen of New York and Philadelphia before that date. This does not for a moment imply that cities of the density of our existing great cities will spread to these limits.'

Before leaving Gottman's concept of *Megalopolis* it is of interest to point out that conditions appropriate to the rise of another large-scale aggregation are faintly discernible in south-eastern Brazil (Fig. 3). Along the trunk route following the Paraiba Valley, which connects the two urban complexes of Rio de Janeiro and Santos-São Paulo, is a succession of rapidly growing industrial centres such as Volta Redonda, Barra Mansa, Resende and others. Though at present considerable stretches of countryside intervene, the merging of some of these towns will occur

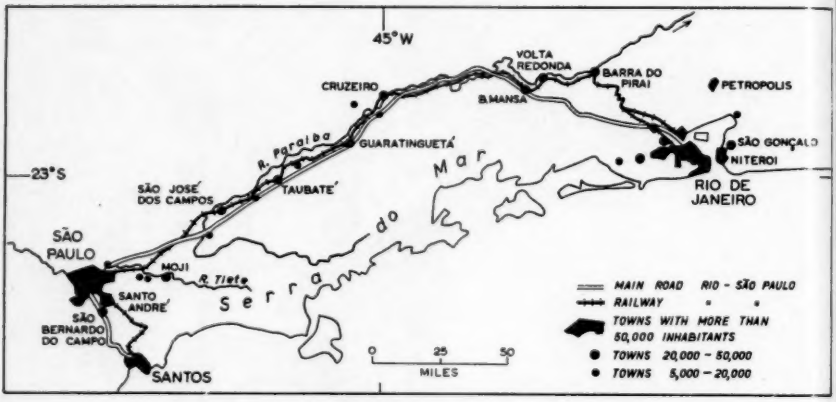


FIG. 3. Industrial centres of south eastern Brazil.

at no distant date, and if Brazil's industrial development continues to be concentrated in this area, future urban coalescence may eventually take place along this 200-mile stretch, producing a densely populated industrial corridor shut off from the sea by the Serra do Mar except at its terminal cities. (14)

TRENDS OF URBAN GROWTH IN THE LATEST PHASE

On the evidence submitted here, urbanisation in its latest phase reveals three general trends. In the first place, more and more of the world's people are becoming town-dwellers, and the rate at which they are doing so is now more rapid than at any time in the past. In this respect many of the less-developed lands are catching up on the advanced countries. Secondly, the world's largest cities are growing faster than those of lesser size. By the process of expansion and intergrowth conurbations are rapidly multiplying, forming in many cases agglomerations of several million inhabitants. Moreover, in areas of dense urban settlement, the tendency towards an ultimate stage, in which the coalescence of these vast entities produces a huge continuous urbanised region is now apparent. Both these trends of a quantitative nature represent, on the whole, an acceleration of town growth in those parts of the world in which urban settlement was well established prior to the period under review. Recent expansion has greatly intensified the pre-existing pattern.

At the same time changes in the direction of urban development have occurred,

thus giving rise to the third, and as yet the least significant, of the general trends. The appearance of towns in parts of the world in which they were previously lacking has in fact proved rather more extensive than Fawcett envisaged in 1937. Many instances of this could not have been foreseen, however, for they are largely the result of political and economic changes brought about by the Second World War and its aftermath. New towns in the Canadian North-west, in the Soviet Far North and Far East; new industrial centres in Inner Mongolia; new ports along the West African seaboard, all can be cited in evidence of a vast increase in the exploitation of the world's resources and of Man's capacity to apply the techniques of urban life to extreme environments. In this respect the facts of urban geography continually yield surprises. Who, at the time of the first Soviet Five Year Plan, would have imagined that the ancient town of Tashkent would soon become larger than Liverpool or Manchester? Who would have suspected that Londrina (Paranà State), founded in 1938 in the midst of the new coffee belt, would celebrate its coming of age this year, having 100,000 inhabitants?

Apart from the beginnings of town development in new areas, urban growth in general remains greatest in the world's older regions of close settlement. It is still mainly dependent upon the movement of people from rural areas and from the smaller to the larger cities. The townward drift is largely the expression of a desire for improved conditions of life, and the opportunities naturally appear greatest in those parts where urban facilities are already deeply rooted. In the process no new equilibrium between rural and urban populations is in sight, for food production, despite a dwindling labour force (except in South-East Asia), is increasingly dependent upon technical improvements in agriculture (15). Today the essential relationship is that between agricultural productivity and urban demands.

From the standpoint of human welfare the question may well be asked, is the present rate or urbanisation excessive? Since the world is not a unit, this question can only be discussed with reference to particular countries. Broadly speaking, it would appear that in countries in which economic development has reached an advanced stage, rapid urban expansion is not in itself to be deplored, whereas in less-developed countries, especially where food production depends on an ill-equipped peasantry, it is likely to be otherwise. Two instances may be noted in which such doubts arise. Throughout Latin America, where population growth is extremely rapid, conditions in almost every country promote heavy migration to the leading cities. Shortage of capital for agricultural improvement, expanding opportunities in urban employment and the high social prestige accorded to city life by all sections of society in Latin America are the chief factors intensifying the flight from the countryside. Unhappily many who succumb to the townward march find its rewards illusory. Low-paid unskilled work, often spasmodic, results in a pitifully low standard of existence in squalid shanty-towns on the city fringe or in evil slums like the *jacales* of Mexico and the *favelas* of Brazil. In India, too, the process of urbanisation, so long retarded, seems now to have begun. The Indian Census of 1951 claims that between 1941 and 1951 the urban population increased from 14 per cent to 17·5 per cent of the total, a gain considerably greater than the combined increase recorded for the two previous decades. This trend can surely prove an advantage to India only if an early solution is found to the two vital problems of food production and the control of population growth.

Functional Trends in Towns

Now let us turn from the general problem of urban expansion to a brief consideration of changes now affecting the individual town. Chief among these from the functional standpoint is the increasing importance of the non-productive compared with the productive occupations. The former category includes the provision of services of all kinds. Service functions have always been an essential feature of true

towns, but their recent extension, both in range and magnitude, has given them a prominence in the structure of urban employment which is continually mounting. In all large centres, administration, the professions, retailing, entertainment and numerous health and welfare services claim an ever-growing proportion of the employed population. Just as in the earlier phases of town development the rise in the food-producing capacity of the rural population enabled increasing numbers to find a livelihood in towns, now, in addition, the speed of manufacturing processes permits more and more people to enter widening fields of employment located in the town. The rapid expansion of service occupations, which employ both men and women, is undoubtedly one of the main causes of the increasing size of large towns. So far as society is concerned, the extension of services in many forms is highly advantageous, for it benefits urban and rural areas alike. In this sense it represents an advance to a higher level in urban functions, through which the community obtains an increasing diversity of satisfactions.

In the U.S.A. there are already fewer workers engaged in the tasks of production than in the service occupations. In Britain we are approaching this position, the proportions of the employed population in the two categories for England and Wales in 1951 being 53 per cent and 47 per cent respectively (16). Considering individual towns, Table II shows the proportion of people engaged in service occupations as a percentage of the total number employed in various centres in England according to the Census of 1951, Industry Tables. For this purpose

TABLE II

Persons Engaged in Service Occupations as a Percentage of the Total Employed Population

	%		%
I. *Eastbourne* (*58*)	78·0	*Truro* (*13*)	79·1
Bournemouth (145)	76·8	*Durham* (*19*)	76·3
Blackpool (148)	71·0	*Exeter* (*75*)	69·7
Brighton (156)	68·3	*Shrewsbury* (*45*)	68·5
Southend (152)	66·2	*Chester* (*48*)	68·2
II. London (3,348)	63·0	*Carlisle* (*68*)	58·2
Liverpool (790)	59·7	*Wakefield* (*60*)	55·3
Newcastle/T (292)	58·0	*Oxford* (*99*)	54·8
Manchester (703)	50·2	Norwich (121)	50·4
Leeds (505)	43·5	*Lincoln* (*69*)	47·9
Birmingham (1,112)	35·2	Northampton (104)	42·6
III. Southampton (178)	62·6	Derby (141)	37·6
Plymouth (209)	62·3	Wolverhampton (163)	37·2
York (105)	56·0	Leicester (285)	36·6
Hull (299)	55·2	Blackburn (111)	35·7
Bristol (442)	54·6	Bolton (167)	34·3
Middlesbrough (147)	50·8	Huddersfield (129)	33·5
Nottingham (306)	44·4	Luton (110)	27·7
Bradford (292)	39·9	Coventry (258)	26·2
Sheffield (512)	37·9		

Note: (i) Towns under 100,000 inhabitants are in *italics*. (ii) Population, 1951 (in thousands), shown in brackets.

Source: Census of England and Wales, 1951. Industry Tables. Groups XVIII–XXIV inclusive (males and females aged 15 and over).

Occupation Groups XVIII–XXIV inclusive have been used, but Group XVII (Building and Contracting) has been omitted on the ground that it is a form of production rather than a service. By arranging the towns into broad functional groups, significant variations become evident.

Large coastal resorts, since their existence depends upon the provision of a particular kind of service, show the highest percentages, ranging from 65 per cent to over 75 per cent. Comparable figures, however, are shown by the smaller non-industrial county towns in which administrative functions are characteristic. Next come the cities of the great industrial conurbations, ranging, with the exception of Leeds and Birmingham, from 50 per cent to over 60 per cent. Here London occupies the leading position. Since the West Riding conurbation is without a dominating city, this may largely account for the low percentage in Leeds, but the much lower figure for Birmingham is less understandable. Somewhat comparable with those of the great cities are the percentages for the larger industrialised county administrative centres. In the third group are representative industrial towns (including four seaports) showing a wide percentage range. Luton and Coventry, however, exhibit abnormally low figures. In both cases these reflect the growth of a single large-scale industry, that of motor-vehicle manufacturing, which up to the present overshadows other urban functions. At Luton, even in the past few years, the net increase in manufacturing employment has averaged over 1,500 persons per annum, while barely half that number have entered the service occupations. With these exceptions, the proportion of people engaged in service activities invariably exceeds one-third of the total number employed and in a majority of cases it exceeds one-half. Thus the industrial town is no longer composed chiefly of industrial workers.

Space-demands Exerted by Office Functions

Among those engaged in non-productive activities, office-workers in particular have expanded so enormously in number that provision for their accommodation raises a problem in all large towns. The forerunner of the city office was the merchant's counting-house. Unfortunately, even until the late nineteenth century, details of its size are obscure, but it generally seems to have been small. In Charles Lamb's day, judged from the fleeting glimpse he gives of his fellow clerks at the East India House, it would appear that a relatively small staff could handle the affairs of one of the greatest trading companies of the time, though admittedly its business was then on the wane. A survey of Liverpool made about 1870 showed that the average number employed in the commercial offices of that city was only four (17). Census returns from 1851 onwards, however, provide evidence of the general increase in clerical workers, and Dr. D. Lockwood has estimated that the proportion of clerks to the total number of employed persons in this country rose from 0·8 per cent in 1851 to 10 per cent in 1951 (18). Further, 60 per cent of office-workers today are females, whereas a century ago there were virtually none. Parallel with this growth the average size of the office and its staff has greatly increased.

More than any other factor, the demands made by office accommodation have intensified the pressure on building-space in the heart of the city. This has resulted in the increasing use of the tall building which was America's solution to a specific problem of urban expansion towards the end of last century (19). In the U.S.A. the depression of the 'thirties brought an end to the erection of the giant structure in its extreme form, and for the past twenty years Brazil has seen the greatest proliferation of the skyscraper. In the city of São Paulo competitive building of this kind has been as frenzied as it once was in New York and Chicago.

The acceptance of the tall building on a modified scale in Europe and the other continents indicates a new trend in urban architecture by means of which the continued expansion of commercial and administrative functions can be met. For such

uses the tall building affords high occupational densities on a restricted site. The rentable floor space amounts to about 70 per cent of the gross area. Thus, allowing for 100 square feet for each office-worker, a structure of twenty storeys on a square base of 100 feet can accommodate 1,400 persons. The new block of twenty-eight floors situated between Knightsbridge and Earls Court in London, to be known as the Empress State Building, will accommodate 2,500 workers.

The revival of the tall building in America during the post-war years in the form of slab-like buildings of metal and glass has made another contribution to urban development, for the slab provides the maximum rentable floor space in relation to circulation space, including staircases and lifts. Unlike the original tower-form skyscraper, this type of structure has quickly been adopted in European cities and elsewhere. Thus the modified tower and the slab are now changing the urban skyline in all parts of the world, even in the less-developed countries of Asia and Africa, for in addition to their functional value they are regarded as symbols of business prestige. Scarcity of sites and resultant high land values may account for their growth in Johannesburg, but hardly in Salisbury (Rhodesia) and Leopoldville. Many of these blocks are erected by speculators as a source of profit, and in view of the high constructional costs it is important that every floor should be tenanted. It is even important to have acceptable occupiers of the ground-floor shops, for whom the term 'prestige tenant' is now freely used in London.

In Europe, including Britain, the redevelopment of decayed or war-devastated cities has provided the opportunity, despite a conservative tradition, to use tall buildings. But it has been adopted on a moderate scale. The reasons for this are many—limitation of capital; aesthetic considerations; architectural conservatism; and even physical difficulties, as in Rotterdam, where deep excavations through peat are necessary to establish foundations. On the whole, new office blocks do not exceed twenty to twenty-five storeys, and only here and there, as in the Pirelli Building in Milan with its thirty-six floors, has anything approaching a true skyscraper appeared.

Among the large cities the two most conservative in this respect are London and Paris. In central Paris building-heights are restricted by the Prefecture to a maximum of eight storeys, this being regarded as in keeping with the historic skyline of the capital. This regulation has thus governed the proportions of the new UNESCO headquarters in the Place Fontenoy and other recent large buildings. (Nevertheless, there will soon be a 600-foot residential skyscraper in Montparnasse, the highest in Europe!) In London, height-restrictions, first imposed after the Great Fire, were relaxed last century and again in 1952. Office-block speculators nevertheless contrive by various devices to 'break the height barrier', to use Sir William Holford's phrase (20), in the process of accommodating the surge of office employees into Central London which now amounts to over 18,000 additional persons each year.

The use of the tall building for dwellings does not concern us here, save to remark that its appearance in Britain for this purpose, so long opposed, is largely as a means of reducing urban sprawl and of preserving residential densities in areas of redevelopment. It may never attain to a florescence comparable with the Hansaviertel in West Berlin.

To the urban geographer the effect of the continued massing of clerical workers into the heart of the city, is to accentuate the differing locations of industrial and service pursuits. While industry becomes more and more foot-loose, administrative and related functions become less so. This contrast is reflected in opposing architectural trends (21). Factory units, in accordance with modern production methods, present a problem in horizontal movement and are designed as one- or two-storey buildings requiring relatively extensive sites which can only be found at a distance from the city core. Office premises, concentrating upon the central business area,

now pose a problem in vertical movement represented by the tall building on small costly sites. Already, however, another note is heard. Further mechanisation of office operations and the greater use of telecommunications may soon make it possible to decentralise such work. A few firms are experimenting in this direction by building offices in suburban districts. On a large scale this would reduce the daily journey to work and lessen the various forms of urban congestion. How then would the tall building fare?

The Problem of Retail Services

Another aspect of the expanding town is the increasing problem of access to the central retail area. Chiefly owing to traffic congestion, in part brought about by the growth of other service functions, the pursuit of retail activities in many cities has become seriously hampered. While a full discussion of the question is beyond the scope of this address, one or two relevant points concerning the position on this side of the Atlantic should be noted. In reconstructed cities like Coventry, Hanover and Rotterdam, as well as in some of our New Towns, the introduction of a pedestrian shopping precinct with adjoining car-parks points the way to an ultimate solution. This measure implies something of a reversion to the traditional market-place and at the same time suggests a stage towards a more precise grouping of functions within the central business area. The increasing significance of subsidiary shopping facilities, which commonly develop into local service centres, has recently been demonstrated in the case of Nottingham (22). These centres represent an important element in the inevitable decentralisation which accompanies expansion.

The Dilemma Created by Transport

Reference to the problem of retail services in the expanding city raises the fundamental issue of communications. As the city grows and its functions become more diverse, the role of transport in integrating the constituent parts and maintaining external connections, increases in importance. Both aspects of this dual role are now equally essential, whereas this was far from the case when nineteenth-century railways promoted the industrial town in which factories and homes were concentrated together. The latest phase of urban expansion is directly related to the development of motor transport. It is motor transport which directly or indirectly accounts for much of the economic and social activity of the present-day city, and it is largely the motor vehicle which has determined the nature and form of recent city extension. It has permitted the dispersal of industry and the spread of residential areas, yet it has also been the means of increasing the importance of commercial and service functions at the centre. Its effect is at once centrifugal and centripetal.

These opposing forces tend progressively to produce extreme conditions, those of intense congestion at the centre and unmitigated sprawl on the outskirts. The control over urban growth now exercised by transport is so great that doubts arise as to the future capacity of the city to discharge its normal functions satisfactorily. Will the great city disintegrate? Not long ago Dr. Colin Clark discussed some aspects of this dilemma in an article to which he gave the eloquent title, 'Transport —Maker and Breaker of Cities' (23). His conclusion that motor transport, despite its economic efficiency, leads to the formation of urban communities, which are in many respects socially undesirable, is clearly justified, but this need not evoke an attitude of Spenglerian gloom as if it portended irrevocable failure on the part of urban society (24). The problem is really one of physical planning and of improved urban organisation through a more rational system of administration (25). The need for action is undeniably urgent, for the forces making for urban expansion and the scale upon which they are now operating cannot be halted.

Conclusion

In broader terms we are faced with the challenge of reconciling economic progress with social well-being within the framework of urban conditions. It is a challenge which requires a vigorous application of the physical and social sciences. The motto of the university in which I am privileged to serve is singularly relevant: *Sapientia urbs conditur*. The insistent demands by an increasing proportion of the world's inhabitants to share the advantages of urban life occurs at a time when science and technology are especially prodigious in conferring material benefits. It should not, therefore, prove beyond the capacity of human wisdom eventually to re-shape the urban environment in a manner which will make it more than ever an instrument for social betterment.

References

(1) Robson, W. A. (1954): *Great Cities of the World*, London. For a general account of the large city, see Part I, 'The Great City of Today'.
(2) *Report of the British Association for the Advancement of Science*, 1937.
(3) Childe, V. Gordon (1950): 'The Urban Revolution', *Town Planning Rev.* (XXI).
(4) Frankfort, H. (1950): 'Town Planning in Ancient Mesopotamia', *Town Planning Rev.* (XXI).
(5) Cornish, V. (1923): 'The Isothermal Frontiers of Ancient Cities', *Scot. Geogr. Mag.* (XXXIX). See also by the same author, *The Great Capitals*, London, 1923, Chapter III.
(6) Fleure, H. J. (1920): 'Some types of cities in temperate Europe', *Geog. Rev.* (X). Also, 'The historic city in Western and Central Europe', *Bulletin of John Rylands Library* (XX), 1936.
(7) Census of the U.S.S.R. 1959. For a report including statistics for all urban centres of over 50,000 inhabitants, see *Pravda*, May 10, 1959.
(8) Population Bulletin. Population Reference Bureau Inc. (XIV), No. 5, August 1958. Washington.
(9) Sources: *Statesman's Yearbook*, 1913 and 1955; *United Nations Demographic Yearbook*, 1957.
(10) Lambert, Audrey M. (1956): 'Millionaire cities, 1955', *Econ. Geog.* (XXXII); Fryer, D. W. (1953): 'The "Million City" in Southeast Asia', *Geogr. Rev.* (XLIII), No. 4; and Linton, D. L. (1958): 'Millionaire cities today and yesterday', *Geography* (XLIII), Nov.
(11) Gottmann, J.: 'Megalopolis or the urbanisation of the Northeastern Seaboard', *Econ. Geogr.* (XXXIII). July 1957.
(12) For a parallel approach to this concept, see Smailes, A. E. (1946): 'The urban mesh of England and Wales', *Trans. Inst. Brit. Geographers*, No. 11.
(13) Wells, H. G. (1901): *Anticipations*. London.
(14) Sternberg, H. O'R. (1955): 'Agriculture and industry in Brazil', *Geogr. J.* (CXXI), Dec.
(15) Fawcett, C. B. (1929): 'The balance of urban and rural populations', *Geography* (XV), June.
(16) Census of England and Wales, 1951. Industry Tables.
(17) Orchard, B. G. (1871): *The Clerks of Liverpool*. Liverpool.
(18) Lockwood, D. (1958): *The Blackcoated Worker*. London.
(19) Tunnard, C. & Reed, H. H. (1953): *American Skyline*. New York. See Part V: 'The Expanding City'.
(20) Holford, Sir William (1959): 'The tall building in the town', *Journ. Town Planning Inst.* (XLV), March.
(21) See Smailes, A. E. (1955): 'Some reflections on the geographical description and analysis of townscapes', *Trans. Inst. Brit. Geographers*, No. 21.
(22) Weekley, I. G. (1956): 'Service Centres in Nottingham: a concept in urban analysis', *East Midland Geogr.*, Dec.
(23) Clark, Colin (1958): 'Transport—maker and breaker of cities', *Town Planning Rev.* (XXVIII) No. 4.
(24) Spengler, O. (1928): *Decline of the West* (trs. C. F. Atkinson). New York. For the author's views on urban society, see Vol. II, chapters 4 and 5.
(25) Self, P. (1957): *Cities in Flood*, London; and Freeman, T. W. (1959): *The Conurbations of Great Britain*, Manchester University Press. These are recent publications giving some consideration to these problems.

HOW MUCH SCIENCE?[1]

ADDRESS BY PROFESSOR JOHN JEWKES, C.B.E.

PRESIDENT OF SECTION F

I

IT IS frequently said that Great Britain is suffering from a shortage of scientists and technologists and of the means for conducting research and development and, since the study of shortages is the main interest of the economist, I propose to examine the reasons usually given for making this statement and to speculate a little about how a community can satisfy itself that it is devoting sufficient of its efforts to scientific and technical matters. As I shall try to explain in a moment, the scale of scientific activities in the country is determined by a very puzzling combination of public and private views, public and private action and, in the last resort, the striking of a right balance will inevitably be a matter of judgment and of intuition. Those who take sides too strongly, therefore, are not likely to give good advice and I fear that, in recent years, some of those who have taken a vigorous part in the campaign for 'selling science to the Establishment' have been prone, with the best intentions in the world, to muddle up good arguments with bad and, paradoxically enough, to push the claims of science against the humane studies by making questionable use of history, economics, statistics and even perhaps educational theory.

I begin with some matters of definition. It has become fashionable to speak of 'science and technology' in the singular as if what was true of one was inevitably true of the other. But the generalisations that can be made about the two in common are few. In purpose, method and appropriate scale of operation they can best be discussed separately and, although they may frequently have to be discussed as one, that is nearly always evidence of the limitations of our knowledge about them. The practice of bundling the two together has had some very odd results in recent years: for example, when the Russians, by a highly competent piece of engineering, put the first sputnik into orbit, this was used as a proof that more money should be spent on science in Great Britain.

A second truism: if we train in the Universities more people in the sciences or in technology then there will be fewer of the ablest segment of the community trained in the other intellectual disciplines. This would only be untrue if the Universities were at present failing in their task of selection, which I do not believe to be the case. If we decide to have more scientists we must pay the price for it; it is an evasion to suggest that we can have more scientists, more technologists, more historians, more doctors, more economists and so on all at the same time. For the question of quality immediately comes in. The proportions of University graduates who fail even now is high (and incidentally it is higher in science and technology than in other subjects). To scrape the bottom of the barrel more vigorously, to set out to produce what is sometimes described as a 'scientific proletariat' would further increase the proportion of failures; unless, of course, University standards are lowered. The right terms, therefore, in which to discuss this whole question is whether the community will gain by having more scientists or more technologists trained at the expense of non-scientists. Some eminent

[1] Address delivered to Section F (Economics) on September 4, 1959, at the York Meeting of the British Association.

scientists have declared themselves in very forthright fashion on this subject.[1] Whether they were right or wrong they were certainly, to my mind, discussing the right question.

The most important matter of definition, however, relates to the meaning of the word 'shortage'. For the economist, a shortage exists when at the prevailing price the demand is greater than the supply. There is a shortage of scientists when, at existing salaries, Schools, Universities, Government Laboratories, Research Associations and Industrial Firms cannot get as many of these people as they would be prepared to engage. In these circumstances it is to be expected that salaries of scientists would rise because of the competition for them. What would be needed and what would follow sooner or later in anything like a free market would be a boost in supply. I propose hereafter to use the word 'shortage' in this sense: it is a condition of the market.

There is, however, a second, much hazier, meaning given to the word in present-day discussion. There is said to be a shortage when those individuals and institutions which actually exercise the demand for scientists—the Schools, Universities, Public Laboratories, Industrial Firms mentioned above—are not demanding enough of them, are making mistakes in not rating sufficiently highly the contribution that such workers can make to the profits of individual businesses or to the national welfare, are not sufficiently 'science-conscious'. In this sense it is not merely the supply but also the demand for scientists which is inadequate. For this situation I propose to use the term 'unmet need'.

As I say, this 'unmet need' is a vague and perplexing concept (although I am not prepared to argue that it is entirely without meaning). It implies that those people and institutions responsible for exercising the demand for scientists do not really know their business as well as some other group of people who, although they are not in this business and stand to lose nothing if they are wrong, draw upon some source of higher wisdom. For instance if a statesman or an economist declares that industry would gain greatly from the employment of more scientists, how does he know? Indeed why should he know better than the industrialist? And if he is confident of his conclusions why should he not go into industry himself and make the large profits which the existing industrialists are neglecting to make? A second reason why 'unmet need' is so slippery an idea is that it is bound up with the distinction between private gain and social gain. It is possible to argue that even if the employment of more scientists by one particular firm will not increase the profits of that firm, yet it will increase the national income. But social gains and social costs are the most difficult things to measure even in a rough and ready fashion.

II

Let us try now, as an exercise, to answer the questions: what evidence is there of (*a*) a market shortage, and (*b*) an unmet need for scientists in Great Britain? By scientists I mean (following the classification of the Ministry of Labour) persons

[1] The late Lord Cherwell, speaking in the House of Lords on November 21, 1956:

'Humanistic studies are agreeable, and were very valuable in their day. But they do not really help the country to survive today . . . The fact remains that the people of this country must be fed and clothed . . . the contribution of a man like Whittle was even more helpful to the people of this country than the efforts of any of the Regius Professors of History in our own Universities.'

Also Sir Alexander Todd:

'To suggest that more than a modest number of those now studying, say, history or literature in our Universities were being trained to the best advantage was not only nonsense but at the present time, dangerous nonsense.'

(*The Times*, January 3, 1957)

trained to University levels in biology, chemistry (other than pharmacy), geology, mathematics, physics and general science.

Let us take market supply and demand first. The number of scientists being turned out by British Universities is on the increase. In 1956–7 the number of degrees and diplomas obtained in pure science was more than twice as great as in 1938–9 and 11 per cent greater than in 1949–50. Between 1955 and 1958 the number of full-time students entering University Institutions for the first time in order to pursue courses in pure science increased by 25 per cent. The output of science graduates is, therefore, certain to move upwards in the next three years. And still further increases are being planned for later years. In the three years 1956–9 the total output of scientists from British Universities was in the neighbourhood of 18,000. This was the supply. What was the demand? Fortunately we have a rough idea of that because in 1956 the Ministry of Labour undertook an enquiry in order to determine the number of scientists already employed in industry, government and education and the number of additional scientists that, in the view of those who employed scientists, would be required in the following three years. The conclusion reached was that by 1959 the net additional demand for scientists would be about 9,500. Even after making any reasonable allowance for death, retirement and emigration, it seems fairly certain that in these three years scientists were being produced by the Universities at a rate commensurate with the increase in demand as estimated by those who can be supposed to be in the best position to judge.

Have there in recent years been increases in the salaries of scientists disproportionate to the changes in the salaries in other professions, which might have been expected if there had been a shortage? The evidence is very scrappy but it seems to point to the conclusion that there has been no such abnormal change in the salaries of scientists. For example, in the PEP Report, 'Salaries of Graduates in Industry', 1957, where a study was made of the salaries paid to a random sample of some 4,000 graduates of 1950, the general conclusion was that there was little difference between the earnings of graduates in arts, science and technology. The Report goes on to point out that the pattern of earnings was 'not well calculated to encourage men to read science and technology rather than history or languages or some other non-technical subject'. The only homogeneous group of scientists for which earnings figures appear to be available at the moment is chemists. The corporate members of the Royal Institute of Chemistry are largely, although not wholly, University graduates. The Institute has conducted several surveys of earnings since the end of the war and these show that the median annual earnings were £1,040 in 1953 and £1,310 in 1956. These earnings do not compare particularly favourably with what is known of earnings in other professions. Nor is the increase between 1953 and 1956 out of line with the increases which have taken place in wages and salaries generally.

Even if there is no market shortage is there nevertheless an unsatisfied social need for more scientists? At least four different reasons are given why the community should have more science and more scientists. First it is said that, quite independently of what kind of career young people may subsequently wish to follow, they should be taught more science in schools and Universities as a part of a good general education. We ought to try to raise the level of scientific literacy. Secondly, it is suggested that more scientific resources should be made available for the purpose of extending man's knowledge of the nature of the physical universe, even if no material advantage could be expected. 'The picture we form in our minds of nature will be the more beautiful for being brightly lit.' Thirdly, it is claimed that more science is needed in order to strengthen our national defences. And, finally, it is stated that more science is a necessity for improving economic standards.

It immediately becomes obvious that the chance of determining 'needs' of this

kind by methods which would carry a commanding logic or would find general acceptance seems to be extremely remote. There are great differences of opinion, even between experts, as to the proper place of science in our general scheme of education. How does a community make up its mind how much it wishes to spend on the acquiring of pure scientific knowledge which may or may not have usefulness in the narrow sense? It is customary to suggest that the extent to which science should be subsidised for the purpose of national defence is a matter which can be left to military experts. In fact that is not the case; military needs have no limit and there must be some point at which, as military expenditure increases, the economy as a whole is so weakened that this expenditure becomes self-defeating. Presumably the decisions under the fourth head can be more exactly determined, or at least they can be left to businessmen, each deciding on the merits of his own particular case whether increased expenditure on science seems worth while. But even there it is not easy to discern any very clear pattern of business behaviour.

Difficult as it may be to reach a convincing decision about needs on any one of these four grounds, when they are looked at together the complexities multiply quickly. The different needs may be in conflict. In the short period, if the community wants more teachers of science it must content itself with less scientists for work in industrial laboratories. Or, in the longer period, if the community decides that it attaches value to extended knowledge of the cosmos, it may be necessary to sacrifice material standards of living for that purpose. More radio telescopes mean fewer private television sets.

Must we then resign ourselves to the idea that the decisions made can never be rational; that action will always have to be taken on but a fragment of all the evidence needed for logical behaviour; and that, having taken decisions, it will never be possible to know whether they were correct or not? Or, on the contrary, can we be confident that, although there can be no precise determination of how much science there should be ideally, yet at the moment there is certainly too little; that although we do not know how far we should go, we can feel confident that we are moving in the right direction. It always seems to me to be an additional enigma of this subject that, despite all its mysteries, some outstanding writers and institutions manage, by somewhat mystical processes, to reach confident conclusions that one line of action is palpably preferable to another.[1]

In the next section of this paper I examine the broad tests which, at various times and places, have been applied in order to determine whether sufficient emphasis is being placed on science. Before doing that, however, it is worth while pointing out that some well informed observers have suggested that Great Britain is not suffering from an unmet need for more scientists.[2] That view gains support from comparisons between the United States and Great Britain.

[1] Thus the British Advisory Council on Scientific Policy, 1956–7, p. 4, says in one breath:
'It is not possible to lay down any proportion of the total national effort on research and development which should *a priori* be devoted to the civil sector.'
and in the next:
'But in our view, the resources devoted to civil research and development have been and still are far too small for a country whose competitive position in world trade is dependent upon the economic development of new products and new processes and where the achievement of a rising standard of living must depend mainly on our success in increasing the productivity of the labour force.'

[2] Thus the late Viscount Waverley, speaking in the House of Lords on November 21, 1956:
'So far as pure science is concerned, statistics appear to show that we are in no way behind Russia, the United States of America or any other country. It is in regard to technology or applied science that we are woefully behind.'
And Lord Simon of Wythenshawe in the House of Lords on November 21, 1956:
'I want to make it as clear as I can that the crux of the position today is not scientists; it is engineers. A Nobel prize winner in physics has recently written: 'The Science departments of our Universities are better and more vigorous than they have ever been in the history of this country. . .; What is wrong in this country is that there are far too few engineers to develop our scientists' ideas as fast and as well as is done in some other countries.'

In the Appendix, I compare in detail the annual output and the existing stock of scientists in Great Britain and the United States. The conclusions to be drawn (and this is indicative of the grave difficulties of making these comparisons even under the most favourable circumstances) depend crucially upon the view that is taken of the relative standing of science degrees in the two countries. If the first science degree is taken as equivalent in Britain and the United States, then America possesses, and is annually producing, about twice as many scientists in relation to population as Britain. If, on the other hand, the first science degree in Britain is regarded as equivalent to the second science degree taken in the United States, then the advantage would lie heavily with Great Britain. I suggest that, surrounded with all these doubts, a reasonable compromise conclusion is that the two countries are roughly in the same position.

I repeat that I have in this section been dealing with scientists alone. It would be useful if one could prepare a similar analysis for technologists, which roughly means engineers of all forms, but, in my opinion, the existing information is not really adequate enough to reach any conclusion here. What knowledge we have, however, suggests that the shortage of, and the need for, qualified engineers in Great Britain may have been exaggerated.

III

What tests have been applied to determine whether the resources devoted to science and to technology are adequate? The extensive literature on the subject reveals four ways in which writers have sought to establish their case:

1. International comparisons: it is frequently asserted that Great Britain is lagging behind other countries, notably the U.S.A. and Russia.
2. Industrial comparisons: if one industry is devoting less effort to science and technology than others, it is presumed that this is evidence of failure on the part of that industry.
3. The establishment of positive correlations between industrial output and the number of scientists and engineers employed in industry. The presumption then is that an increase in the number of scientists and engineers will increase industrial production.
4. The measurement of the net return, for specific inventions or for particular industries or countries, of investment on research and development.

International Comparisons

Although there are honourable exceptions, recent international comparisons of the scale of scientific effort must rank among the most reckless of all statistical exercises ever made. (Indeed they suggest that what we are most short of are competent and responsible statisticians.) The common argument is that Great Britain is falling behind the United States and the United States is falling behind Russia. But why should it be assumed that Russia is doing the right thing and the other two countries the wrong? From the experience of the last quarter of a century it surely cannot be denied that Russia is capable of inflicting upon herself massive misdirections of her resources. Why not in this case?

What is meant by the statement that one country is falling behind another? What is the right basis for comparison? For example, I have already suggested that, if some allowances are made for differences in educational standards, the number of scientists being turned out annually by American Universities per thousand of the total population may not be very much higher than in Great Britain.

But these statistics of graduates can be looked at in other ways. For example, in 1956, 25 per cent of those who graduated with the bachelor's degree in Great Britain graduated with science degrees; whilst in the United States only 4 per cent of those who took the first degree took a science degree. The reason for this is a simple one: the annual output of University graduates in the United States in non-scientific subjects, in proportion to the population, far outstrips that in Great Britain. Is Great Britain, then, in a more or less favourable position than the United States?

Or again, it seems to be roughly true that the money expenditure in Great Britain on industrial research and development as a proportion of national income is about as high as in the United States. Does this mean that the British position is satisfactory? Some may argue so. But others may argue that the British proportion is relatively high only because the national income is low and the national income is low only because insufficient funds in total are devoted to research and development. The suggestion would be that if Great Britain spent more on research and development then its national income would increase at least *pari passu* and the proportion between expenditure on research and development and the national income would still remain the same. If there is anything in this line of reasoning, then the present situation in Britain could be regarded as highly unsatisfactory. In any case, is it safe to regard the *costs* of research and development as a proper measure of fruitful results? How much truth is there, for instance, in the statement often heard that research in America is carried out on a much more lavish scale than in Great Britain?

I will not elaborate on the other statistical snags in these measurements. What is a scientist or an engineer? To what extent is a man who 'comes up the hard way' necessarily inferior to a formally trained man? These difficulties are great enough when comparing two countries, such as the U.S.A. and Britain, which are similar in many respects. But when we bring into the comparisons Russia, where social institutions are so different, where independent observers are not allowed to move freely (and where, of course, a good Marxist, by definition, would not be above the use of statistics for the purpose of misleading the decadent bourgeois) then the foundations for conclusions become even more rickety.

But taking the figures most commonly employed, there are some formidable obstacles in extracting real meaning from them. For example, it is said that Russia and the United States have about the same number of qualified engineers. It is also said that the total industrial output in Russia is about one third that of the United States. It follows arithmetically that industrial output, per qualified engineer is thrice as great in the United States as in Russia. Does this mean that Russia makes a prodigal use of qualified engineers or that its engineers are inefficient? Or is it that there is some inherent weakness in the Russian industrial system which makes it essential to employ many more qualified engineers per unit of output than in Western countries?

The Correlation between Industrial Output and the Number of Scientists and Technologists

The only attempt known to me to establish a link between the number of scientists and engineers in employment and the growth of the economy and, in this way, to predict the future need for scientists and technologists is that of the Committee on Scientific Manpower.[1] Their argument is worthy of close scrutiny. There are three stages in it which can be set down in the actual words of the Committee's Report:

[1] 'Scientific and Engineering Manpower in Great Britain', Office of the Lord President of the Council and the Ministry of Labour and National Service, 1956.

1. 'There is a definable relationship between the rate of increase of industrial production on the one hand, and the number of trained scientists and engineers employed by industry on the other.'[1]
2. 'It is more reasonable to base our projections of the likely need for scientific manpower on the assumption that demand within each industry will, on the average, increase in direct proportion to increases in industrial output than on some even more arbitrarily chosen relationship.'
3. 'We were advised that it would be appropriate to work on the basis of an average increase of industrial production at the rate of 4 per cent per annum.'

If, therefore, the number of scientists and technologists is linked to industrial production in this way and if industrial production is to increase at the rate of 4 per cent per annum, then a basis exists for determining the need for the number of scientists and technologists in the future.

This approach is perplexing for more than one reason. Which is supposed to be cause and which effect in this correlation? Is it being suggested that the number of scientists and technologists is the crucial determining factor in economic growth, so that if we do not have a 4 per cent increase in the number of scientists and technologists we cannot possibly enjoy a 4 per cent increase in industrial production? Actually the annual percentage increase in industrial production between 1955 and 1958 was not 4 per cent; production did not increase at all in this period. But the number of scientists and technologists certainly increased. Does this mean that there were too many scientists and technologists produced in the period? If not, what becomes of the assumption that there is a definable relationship? If so, and if the crucial mistake made was in the assumption of a 4 per cent increase in industrial production per annum, what is the point of trying to predict the future annual requirements of scientists and technologists by basing it upon another prediction, that of the probable increase in industrial production, which is no easier to make than a straight prediction out of the blue of the number of scientists and technologists that will be required?

An even more puzzling point is that this Committee, along with other authorities, accepts by implication one assumption for which there appears to be little evidence and which is highly pessimistic in character. The assumption is that, since the number of scientists and technologists moves in step with industrial production, output per head of scientists and technologists will never improve, that whatever economies are made in the future they will not be in that particular type of labour. If this were true it would be a striking fact that scientists and technologists could economise in everything but themselves. I do not see why this assumption is made. And I suggest it is pessimistic because, if we accept the idea of a 4 per cent annual increase in industrial production, a short calculation shows that the number of scientists and engineers in Great Britain will have to increase from about 120,000 in 1955 to 5,171,000 in A.D. 2050. That is a lot of scientists and technologists.

Inter-Industry Comparisons

Some authorities[2] seek to establish a case for more extensive industrial research and development by pointing out that some industries spend less than others on research and development and by assuming that all industries would gain by raising

[1] The evidence given in support of this statement is very sketchy. In the United States, where a run of figures of industrial production and the number of engineers exists from 1890, there is no consistent relationship. Thus in the decade 1930-40 industrial output increased 0·15 per cent for each 1 per cent increase in the number of engineers; in the decade 1940-50 industrial output increased 1·2 per cent for each 1 per cent increase in the number of engineers.

[2] See in particular J. K. Galbraith, 'The Affluent Society', p. 99, and the British Annual Report of the Advisory Council on Scientific Policy, 1956-7, p. 5.

themselves to the standards of the highest. Now different industries vary greatly in almost every imaginable sense: in capital investment per head; in the raw materials consumed per unit of output; in the types of labour employed; in the methods of financing new expansion; in the extent to which they buy finished or semi-finished parts from other industries; and so on. Nobody doubts that these variations represent the proper responses of different industries to the different circumstances which face them. Why then should it be assumed that it is a golden rule, an inflexible uniformity, that, in proportion to size, every industry should spend the same proportion on research and development or devote the same proportion of its labour force to these ends?

The Measurement of the Net Gain arising from Research and Development

In much recent writing the practice has been common of quoting the *costs* of research and development as a measure of the returns to them, a practice all the more illegitimate because it is in the case of research and development that costs and returns are most uncertain and most likely to fluctuate from time to time and case to case. There have, however, been one or two recent commendable efforts to try and strike the balance between costs and returns. Thus Z. Griliches, in the *Journal of Political Economy*, October 1958, 'Research Costs and Social Returns: Hybrid Corn and Related Innovations', has carried out a fascinating study of the history of the introduction of hybrid corn in the United States and, after trying to determine on the one hand the whole of the costs of the research and development which led to it and, on the other, the net increase in the value of the corn crop as a consequence of this innovation, has reached the conclusion that as a minimum the social rate of return on the research and development of hybrid corn was not less than 700 per cent. There is a wide field for other similar studies but the inherent difficulties of generalising from such cases must always be borne in mind. In any specific case, the costs may be so widespread both in space and time that it is virtually impossible to identify and total all of them; correspondingly the net advantages of an innovation may spread out in so many directions as to defy measurement. More important, one cannot judge of the general effect of research and development by adding up the successes; there are many more failures than successes.

Nevertheless, as it seems to me, we have here the right kind of question to ask. If nothing had been spent directly on technical progress in the past two decades how much poorer would we be than we actually are? We can, of course, never give a precise answer because it is not possible to isolate from many other forces the specific influence of technical innovation. But orders of magnitude, bearing a rough similarity to the conditions that exist in some Western countries, can be indicated. Let it be assumed that net national output per head is increasing at 2 per cent per annum and that the national expenditure on scientific research and development is of the order of 2 per cent of this output. The causes of the increase in output are various: the use of more capital equipment; improved organisation of existing resources; increased efficiency of labour quite apart from any increase in the use of equipment and, finally, technical innovation. If one-fifth of the annual increase in national output could be attributed to innovation, then the rate of return on the expenditure on research and development would be 20 per cent; if one-tenth of the increase in output could be attributed to this factor, then the return on expenditure would be 10 per cent; if one-twentieth, then the return would be 5 per cent. We cannot make a choice with any great confidence between these different possible answers. But, before we too readily accept the higher, optimistic figures, some sobering facts should be kept in mind.

One is that although there has been an enormous increase in the United States

in the sums expended on industrial research and development since 1930, when the modern industrial research laboratories began to make their appearance, there does not seem to be any strong evidence that this has made steeper the general upward trend in output per head.[1] And the second is that if we compare the experiences of the different industrial countries in the period since 1945, or in any part of that period, there does not seem to be any very obvious correlation between the rate of industrial expansion and the resources devoted to scientific and technological effort. In relation to their size, the United States and Great Britain have probably spent most on research and development; but they have not been the leaders in the rate of economic growth. Conversely, Germany and Japan and some other European countries have shown the biggest increases in industrial production per head although, from any information available, they have not distinguished themselves in scientific and technical expenditures.

IV

My principal conclusion is that we should go on searching for better criteria for determining how much the community should devote to science and to technology. I have no doubt that when everything that can be done has been done in devising objective tests for guiding public policy, much room will still be left for intuition, for judgment, for common sense. I would be the first to admit that the process of shuffling resources about until something like the correct balance is struck is not, in itself, a scientific procedure and certainly not one in which scientists should be allowed the last word.

If, however, there have to be guesses the more informed they can be the better. To my mind we derive no help from such statements as that 'modern science and technology is the greatest force for good or ill in the world today' or that 'scientists and technologists have a special responsibility, since it is their genius and their skill which alone can bring the material basis of happiness within the reach of all'. These are surely myopic misinterpretations of our world in which religious, political and social (and not scientific) ideas are the great moulding forces.

For those whose task it is to put science and technology on the proper map and in its proper place, the following points are perhaps worth considering.

1. Whilst no one would wish to deny that technology and science (probably in that order) have contributed much to the raising of standards of living in the last two centuries, there is a disposition in these days to exaggerate the contribution they have made and to underestimate that made by new social organisations and institutions. New ways of collecting capital for investment; new systems of controlling currency and banking; new market organisations for bringing goods and services to the right places at the right times; new conceptions of the virtues of free trading; new legal and administrative arrangements for curbing monopoly; new legal codes and systems of arbitration enabling trade to be carried on more securely and more speedily; in their totality

[1] Thus M. Abramovitz: 'It is not clear that there has been any significant trend in the rates of growth of total output and of output per head.' 'Resources and Output Trends in the United States since 1870', National Bureau of Economic Research Occasional Paper No. 52; and J. W. Kendrick, after suggesting that there was a significant acceleration of productivity advance from the end of World War I as compared with the prior two decades, goes on 'there does not appear to have been either further acceleration, or retardation, in the primary trend rate of increase in total factor productivity since 1919'. 'Productivity Trends in Capital and Labor', National Bureau of Economic Research Occasional Paper 53.

these social discoveries may have contributed just as much as the technical inventions and scientific discoveries of the period.

2. Much loose talk about 'the second industrial revolution' is leading us to overstress the potential material benefits of recent scientific discoveries. Atomic energy, to take the most spectacular case of all, must still rank as a very heavy debit item in this scale. For, as a result of it, fearful peoples everywhere are sacrificing their standards of living for the purpose of creating modern weapons of war or systems of defence against them. As for the peace-time uses of atomic energy, all that we have are promises, which in recent months have become increasingly tentative, that at some unidentified future moment electricity will thus be generated at a cost as low as the present cost of producing electricity by burning oil or coal under boilers.

3. It is by no means clear that for those countries with urgent short period economic problems, such as intractable balance of payment difficulties or levels of poverty which are politically explosive, more science and technology should have the highest priority. It is usually said that in order to increase British export trade the first need is for more vigorous and better trained salesmen. It is rarely if ever said that British products are failing to sell abroad because of the lack of qualities which they might have possessed if our science had been more advanced or our technology more progressive. In the other field, I doubt whether the first need of the undeveloped parts of the world is for more science and technology; indeed they cannot utilise fully the existing stock of knowledge. On the contrary, what they need above all are more men of the administrative and managerial type and the pervasive spread of specialised skills of all kinds which Western countries take for granted.[1] India, in particular, seems to me an area where administrative acumen and not more science is the top priority; certainly in that country in recent years the shortage of economists who understood properly the limitations and pitfalls of central economic planning has exposed the economic system to violent stresses that it could well have done without.

4. When something is in short supply the most useful immediate step that can be taken is to economise in the use of it to the utmost. It is, therefore, of extreme importance that the scientists and technologists we already have should be employed to the best effect. I wonder whether that has been true in the recent past in Great Britain.

5. Striking the right balance as to the number of scientists and technologists calls, as I have said, for both public and private decisions. Errors, carrying with them serious possible consequences, may arise if both types of decision are not made with an eye on the market. Governments may make provision to encourage more young people to train as scientists but, in the last analysis, it will be business men who will have to employ most of them. There are reasons for supposing that, as a result of a shortage, the demand for scientists may snowball in a way which will make likely a surplus in the future. If, for example, there is a sudden increase in the demand for scientists in industry then, since the total supply cannot increase instantaneously, the first

[1] Lord Heyworth, in his annual speech in April 1959, spoke of these problems of the backward countries:

'There is no pattern of upbringing, no system of education, to develop the outlook and specialised skills which we must look for in countries like this. We cannot do a very great deal to improve matters because the development of patterns of society and ways of thought is part of a nation's historical development which no single firm could massively influence.'

direct consequence would probably be that scientists teaching in schools and Universities would be drawn into industry by the higher salaries offered there. So that just at the time when more science teachers were required to augment the annual supply, fewer would be available. The boom would be intensified. And if efforts are made to meet the shortage quickly, then the annual output of new scientists might easily be raised to the point which was too large to meet normal requirements when the backlog had been met.

Let me illustrate in a few ways what I mean by 'keeping an eye on the market'. First, it is a good working rule to suppose that a business man knows his business better than anybody else. It is to be feared that the vigorous propaganda from outside for more science and scientists in industry, especially when costs can be set against taxation at present high rates, has sometimes led to industrial research laboratories being established which have had little purpose or value. Second, if the demand for scientists does increase, it is desirable that the salaries of scientists should be allowed to rise: for this at once tends to damp down demand and to increase supply. In this connection I cannot help but feel that the general policy in British Universities of striving to maintain income equality among the various faculties is short sighted and indeed self-frustrating. *If* the Universities accept the contention that there *is* a shortage of scientists and that there is a case for swinging the balance somewhat in favour of science in the Universities, then it is inconsistent to prevent the salaries of scientists from rising in relation to other University salaries. And the principle of equality, of trying to pursue a given policy in defiance of the market, is also self-defeating for it means that the Universities, for a given salary, will get lower quality people in the faculties short of teachers than in other faculties. Third, if Government Departments and businesses really consider themselves short of scientists they should be prepared to narrow the margin between scientists' salaries and the higher salaries usually given to administrators (often scientists turned administrators); conversely, if they deem it wise not to narrow this margin, they should accept the logic that it is administrators who are in short supply and not scientists.

6. As it seems to me, the recent boosting of science has taken the form of arguments which might easily be fatal in the long run to the very existence of the autonomy of science. The doctrine has been widely spread that, even where scientific investigation is not directed towards some specified, materially useful end, yet it can be confidently assumed that it will more often than not have such a result. But if the public, acting through its Government, succumbs to such a meretricious appeal and puts down its money for what has been spread before it as a sound investment, it will not unnaturally look forward to a return. It will, not unreasonably, expect that scientists should devote themselves largely to those investigations most likely to lead to material gains; it will expect that, to such ends, scientists will accept public guidance and control. In thus 'seeking to sell science to the Establishment' scientists may also sell themselves to the Establishment. Fortunately the doctrine is both erroneous and unnecessary as a defence of the place, the growing place, of science in any cultured community. Erroneous because, as an observable fact, the overwhelming mass of scientific thought and observation in the Western world was never designed to bring, has not brought, and is highly unlikely ever to bring the slightest improvement in material standards of living. This, of course, is not a confession of failure. It is simply one way of asserting that the ultimate purpose of science is not to cater for the lower claims of material progress, where its yield is uncertain, fluctuating and sometimes even negative, but to satisfy the higher needs of knowledge for its own sake, where its returns can hardly ever fail to be positive.

APPENDIX

1. *The Stock and the Annual Production of Scientists in the United States and Great Britain*

The comparison of the existing numbers and the annual output of scientists in the United States and Great Britain is a hazardous undertaking for many reasons, but for two above all others:

(i) In Great Britain the only figures of existing stock relate to 'Qualified' scientists. This includes University graduates together with the corporate and graduate members of certain professional institutions and the associates of certain educational institutions. But, generally speaking, the level is that of the University graduate. In the various surveys in the United States it appears that a somewhat lower standard than this has been normally adopted. Thus in the U.S. Census of Population, Occupational Tables, it appears that, in the past, a considerable proportion of 'Chemists' have not had four years of College (*The Demand and Supply of Scientific Personnel*, D. M. Blank and G. J. Stigler, p. 11). In more recent surveys by the National Science Foundation a Scientist is defined as one 'engaged in scientific work . . . at a level which requires a knowledge of . . . physical, natural or mathematical sciences equivalent at least to that acquired through completion of a 4-year professional college course'. This clearly would make it possible to include those who were self-educated or had come up 'the hard way'.

(ii) In both countries there are, of course, statistics of the annual number of graduates in the important science groups. But is the first degree, the B.Sc. in Great Britain and the B.S. in the United States, of the same standard in the two countries? It seems impossible to be dogmatic about this. The level of achievement demanded for the first degree varies more widely between one educational institution and another in the United States than in Great Britain. Some observers have gone so far as to assert that the B.Sc. in Britain should be compared with the M.Sc. in the United States (e.g. 'Universities and Industry', Productivity Report: Anglo-American Council on Productivity, pp. 11, 12). Without going as far as that, it seems reasonable to suggest that the British first degree is of a higher standard than that in the United States.

2. *Annual Output of Graduates in* 1956

The figures for the two countries are shown in the Tables below.

GREAT BRITAIN

First Degrees Awarded in Pure Science Faculties, 1955–6

Honours	
Chemistry	1,027
Physics	624
Mathematics	465
Total Degrees[1]	4,920

[1] Including Pass Degrees.

Source: University Grants Committee.

UNITED STATES

Earned Degrees Conferred at First and Second Level, 1956

Field	Bachelors' and First Professional Degrees	Second Level Degrees
Chemistry	6,178	1,164
Physics	2,335	742
Mathematical Subjects	4,660	898
Total[1]	28,898	5,312

[1] i.e. Biological Sciences, Mathematical Subjects, Physical Sciences.

Source: Statistical Abstract of the United States, 1958.

The conclusions which will be drawn from these tables will depend greatly upon one's judgment of the comparative standards of the first degrees. If the standards were the same then, taking together Chemistry, Physics and Mathematics as the most clear-cut group, the United States, with a population three and a half times greater than that of Great Britain, would show an output of graduates six and a half times greater. If the British bachelor's degree corresponded to the U.S. master's degree then the United States would show an output of graduates only about one-third greater than the British. If the truth lay somewhere midway between these two assumptions, it would suggest that, after allowing for the different size of population, the output of science graduates was about the same in the two countries.

3. *The Existing Stock of Scientists*

Ideally, it would be desirable to compare in the two countries the total number of scientists employed in all tasks, the number employed in industry and, within the number employed in industry, the number employed in research and development where the scientist is engaged upon the tasks for which he has been scientifically trained. The nearest approach to this ideal is provided in the tables below.

GREAT BRITAIN

Qualified Scientists Employed by All Authorities and in Industry, 1956

Qualified Scientists	All Authorities[2]	Industry
Chemists	20,692	13,195
Physicists	10,484	4,132
Mathematicians	11,482	1,387
Total	51,228	19,468

[2] Central Govt.; Local Authorities; Education and Industry.

Source: 'Scientific and Engineering Manpower in Great Britain', 1956.

UNITED STATES

Scientists Employed by All Authorities; in Industry and on Research and Development in Industry, 1954

	All Authorities	Industry	Research and Development in Industry
Chemists	—	60,000	26,800
Physicists	—	7,500	4,800
Mathematicians	—	6,400	2,500
Total	290,000 (?)	145,000	52,000

Source: 'Science and Engineering in American Industry': 1953–54 Survey, National Science Foundation.

Here again we reach the conclusion that with three and a half times the population the United States appears to have six times the number of scientists possessed by Great Britain. That margin would be reduced in proportion as the standard of 'scientist' were lower in the United States.

THE CRITICAL IMPORTANCE OF TRANSPORT AND COMMUNICATIONS[1]

ADDRESS BY SIR EWART SMITH, F.R.S.

PRESIDENT OF SECTION G

THE advances of physical science can, in general, only be put to effective use through some form of engineering, which thus stands in a very special position between these sciences and the community. Due to this, and because of the immense and ever-spreading range of both pure and engineering science, I found it difficult to select a subject for this talk, when I had the honour to be invited to serve as this year's President of the Engineering Section.

I have chosen to speak on Transport and Communications for several reasons, not least because in the modern world transport affects the citizen and the engineer at every turn. This joint interest is obvious alike from the daily press and the engineering journals. The subject is one of immense complexity that bristles with technical, economic and political problems on all sides. It is a field where private and public interests often appear to be at variance, and where Governmental control or action has usually been involved to some extent. The Roman roads to Eboracum were not built by private enterprise, but conversely it is difficult to imagine the Government of 1826–7 deciding to build the Stockton and Darlington Railway as a charge on the Exchequer, though, even then, Parliamentary sanction had to be obtained!

York has been an important centre of communications for some 2,000 years, and this is another reason why it seemed appropriate to take Transport as the main theme for this meeting as well as for my address. Many of the papers that are to follow deal with particular aspects of that subject, and they will be given by specialists having a competence and knowledge that I do not possess. My own aim is to express some general and provocative thoughts as a challenge to our sense of urgency; urgency in comprehensive planning, in decision, in execution and, not least, in training the engineer-scientists necessary for effective action in this as in other activities.

Where I make criticisms, they are intended to be objective and constructive, and in no way directed against individuals or organisations in the present. Indeed it is very clear that many of our shortcomings in the whole field of transport have their roots deep in the past, before those now in authority were in any way responsible. Much more is now being done and, technically, done well, but my plea is for a still bolder approach to our transport problems.

SCOPE OF THE SUBJECT

In its widest sense, Transport and Communications covers two broad concepts: first the physical movement of people and goods, and secondly, the conveyance of information. In theory, at least, this includes the transfer of knowledge and ideas, and thus the whole field of education.

Although one is a physical and the other a non-material process, there are in fact basic similarities between them. Both go to the roots of civilised existence; both require a very advanced degree of organisation and of communal effort, if they are to be effective by modern standards; the demands on each are changing

[1] Address delivered to Section G (Engineering) on Friday, September 4, 1959, at the York Meeting of the British Association.

at high speed, and both are absorbing an ever-increasing proportion of the nation's resources; both tend to be trammelled by the past and by the conservative attitude that derives from long existence. In passing, it may be remarked that just as the standard rail gauge is the same as the track of Roman chariots, some of our educational methods still appear to take too little account of the changes in the balance of knowledge and culture that have taken place in the last two hundred years.

We cannot now change the rail gauge, but we can and should press forward with the modernisation of our educational system. By this I mean that all intelligent adolescents should be given a balanced education at school, covering *both* Science *and* the Humanities, and avoiding intensive specialisation at that stage; that University education should be greatly and steadily extended, and that we should face the longer period of such training that is now necessary for the Applied Sciences at least. Every other advanced country has recognised this need, and almost without exception they train a far higher proportion of their brighter citizens in engineering science than do we in Great Britain. This is despite the fact that our proportional need is greater than theirs.

It would be tempting to explore this linkage between transport and education from many angles, but this is certainly beyond the range of this talk and of my ability. Suffice it to point out that they do tend to march together, and the vigour of their progress is no bad measure of a nation's vitality at any time. Certainly under modern conditions, transport methods and systems cannot progress and flourish unless there is recruited to their work a sufficiency of highly educated and able people to meet their technical and managerial needs.

The Role of the Engineer

In the mid-nineteenth century we had the most extensive and efficient transport system in the world, by land and sea; it was an essential complement to our rise to pre-eminence in industrial manufacture of every kind. The creation of this system, like the rise of productive industry, was primarily due to the inventive genius of our engineers and the vigorous application of their ideas to practical ends. But they did more than invent, design and construct in the technical sense, for in large measure they also organised the business sides of the ventures they had conceived. Watt, Brunel, the Stephensons, Bessemer and Parsons are cases in point.

When, today, we compare transport at home and abroad, we can hardly be satisfied that we have kept pace with the general advance of the last thirty years in regard to our road and rail systems. I believe that our present position is in part due to the fact that in this country professional engineers have tended to become increasingly concerned with the purely technical aspects of their work, and to confine themselves to research, and to the design and construction of projects that non-technical managers and administrators ask them to undertake. Abroad, the engineer of appropriate type more often undertakes a much wider role, including a share in administration and general management.

We engineers are ourselves partly to blame for this converging trend to more specialisation, because of the sheer interest and satisfaction that so often stems from our work. In part, too, it is the result of the woefully small numbers of scientific engineers that have been trained in Great Britain relative to the need for the immediate technical jobs that have to be done. But whatever the cause, the inevitable result has been a tendency for engineers to play a relatively smaller part in affairs outside their specialist role. Given wide training, and by the very nature of his activities, the engineer should often be well placed to decide *what* ought to be done, as well as *how* it should be carried out in technical detail. To say that is

not to argue that the technologist should be 'on top' rather than 'on tap' as the administrators might prefer; it does imply that there should be a better balance than now exists in which the well-trained engineer would often take a much larger share in general management. The advance of science and technology is steadily creating new sectors of specialised knowledge, but this only enhances the need for a proper supply of scientists and engineers with wide understanding who can link these specialist activities together in an effective way.

In support of this thesis, I would cite the rapid progress of development in atomic energy, in aircraft, in electronics, and the electrical industry generally: in all of these the scientific engineer has not only designed, but largely organised and managed. Where mistakes of policy have been made in these fields, they can often be traced to requirements, or decisions, determined by people with little or no technological background. In the heyday of railway development in this country, and more recently in France, where such great strides have been made in the post-war years, the engineers were largely involved in policy decisions and in general direction, in addition to their technical responsibilities. Because in some fields of transport engineers have become largely confined to purely technical work, I believe there has been a real loss to the community of the sort of vision and courage that the pioneer engineers displayed and that those in some of the newer industries show at the present time.

The Importance of Transport and Communications

No one will deny that the general means and standards of transport and communications are important; this is certainly the feeling when one's train is late or when held up in a road traffic jam. But perhaps I should attempt to justify my use of the term 'critical' in this connection.

(1) The modern industrial state is utterly dependent for its daily bread and very existence on the regular functioning of its transport system.

(2) The standard of life and the competitive power of a country, such as ours, depends in large measure on the speed and efficiency of its transport, which, directly and indirectly, absorbs a large proportion of the nation's effort.

(3) The general state of transport exercises a major psychological influence on the community. It is as it were a barometer for all to see, that indicates the technical and organisational ability of a country, and the level of its vigour and rate of progress. For visitors, such an appraisal is usually conscious and immediate; for the inhabitants it may often be subconscious, but its effect is no less important.

So far as I am aware, there is no satisfactory official estimate of the proportion of the national effort that goes directly or indirectly into home-based transport and communications by land, sea, and air. An examination of the information available indicates for 1957 a gross figure of the order of £4,750 million; it may well have been over £5,000 million, if all costs could be ascertained. This total is made up of the operational and capital costs for roads and road vehicles (including road accidents), for the railways under the British Transport Commission, for civil aircraft and aerodromes, for British shipping, docks and harbours, and for Post Office expenditure where not otherwise included. These figures take no account of loading and unloading or adminstrative costs internal to factories; nor do they make any allowance for the value of the time spent by passengers in public and private vehicles, a very large figure indeed.

In 1957 the gross national product was approximately £19,000 million, so transport appears to account for not less than 25 per cent of the whole national

effort. In material terms, therefore, there can be no doubt about the huge total effect of transport on the economy.

The basic facilities for transport in the form of roads, permanent way, stations, docks and aerodromes, as the case may be, demand space and capital works of civil engineering on the largest scale. By the very nature of these fixed installations, they can only be created slowly and, once developed, alteration is of the utmost difficulty. The need for vision in technical planning and for continuous capital development to keep pace with requirements increases with the complexity and acceleration of technological change. Here is an acid test of the community, a test of morale, of vitality and leadership; is there willingness to forego some present consumption to provide the essential capital needs of the future? Can we, as a nation, feel very happy that we have done very well in this respect, and have our priorities been well chosen? Have we as engineers raised our voices as strongly as we should, or have we been so immersed in our own particular work that we have let these matters go by default? In this respect it was particularly encouraging to see the bold £142 million scheme for a London ring road recently put forward jointly by the engineers of the 28 Metropolitan boroughs.

The mention of priorities inevitably raises wide issues of organisation, including national and local administration and the allocation of finance annually between competing departments. No one would suggest weakening Parliamentary control of finance and taxation, but the traditional system of rigid yearly grants works against technical efficiency and inflates total costs for major projects. It is good to note the increasing trend to declare long-term *rates* of expenditure, as for the roads, or to the approval of schemes as a whole, as in the Railway Modernisation Plan.

But it is in connection with the priorities of capital works that the gravest doubts occur. For example, within the bounds of our present review, we find capital allocations to the Post Office of approximately £100 million per annum, whereas the roads have yet to rise to the promised £60 million per annum. May one hazard an explanation of the smaller sum for the roads as being due to the Treasury's view that the Post Office can show a very proper and measurable return on its capital, but that roads are regarded as an unproductive overhead expense? If there is any truth in this thought, it points once more to the need for a much greater influx into the Civil Service of people with technological understanding, and a better appreciation that ample and efficient overhead facilities, whether of competent, well-trained staff or in the form of material facilities, are a necessary foundation for efficiency in the modern world.

At the risk of re-stating what is obvious or already well known, I should like to touch on a few figures and factors that seem to underline the need for greater imagination and boldness in plans and in expenditure than has yet been shown in our transport systems.

The Roads

Since 1946 the number of licensed vehicles has increased at an average rate of 8·2 per cent per annum, with no sign of change. From 1920 the rate has been of that order and has never fallen below 5 per cent per annum except for the 1930 depression and the war years. On existing trends, the present 7 million vehicles will double in less than ten years. Should this happen, we should even then have only 1 vehicle per 3·6 inhabitants, against the U.S.A.'s figure of 1 per 2·6, and there the ratio is still rising at 5 per cent per annum. Traffic, i.e. vehicle miles, is growing generally at over 7 per cent per annum, and against this the expenditure on new roads and major improvements has been:

	million (1)
1938/39	£17
1948/49	£5
1950/51	£6
1952/53	£5
1954/55	£8
1956/57	£22
1957/58	£29
1958/59	£50–60
1959/60	£60 (proposed)

But when regard is had to the fall in the value of money, even the £60 million is no more than the pre-war rate of expenditure, and our effective rate of maintenance is rather lower than pre-war. In 1939 there were 3,100,000 licensed vehicles, and already by 1957 7,400,000—need more be said?

There is the double problem of urban congestion and inefficient inter-urban linkage. At present most of our efforts are directed to the latter, but it will be of little benefit to speed traffic between towns, if it is to be bogged down at either end. Since Kingsway was built fifty years ago, central London has had no new main thoroughfare till the first part of Route 11 was opened this year; the first modern flyover in London is still not complete. In comparison, Brussels, under the spur of last year's Exhibition, went far in two years to relieve her traffic problems by building several miles of new road and a number of under- or over-passes. It is reckoned that much of this work will be repaid by savings within five years. Of course, the financial and sentimental difficulties of urban improvements are very great, but we must decide whether we wish to become a museum piece, or keep our place in the modern world. Where, for reasons of history or architecture, there are streets or areas in our ancient cities and towns that we wish to preserve unchanged, these should be determined and the traffic flow strictly regulated or banned to give quiet pedestrian precincts. Similarly, we must be ready to provide for vehicular and pedestrian traffic at different levels. If ring roads and radial feeders are to be effective, they will often have to be completely new highways. Too often we select streets that connect up somehow and, by calling them a 'ring road', imagine that our problem is solved.

After the Great Fire, London missed its opportunities in spite of Wren's vision. After 1939/45, we had Sir Patrick Abercrombie's Greater London Plan, but we had, too, a multitude of Authorities, Departments and Committees, who gave lip-service to planning. In the result we have done little of a major nature to retrieve the lethargy of the past fifty years. Indeed, far from providing freer movement, we have allowed the meanderings of our street system to silt with standing vehicles, till at times the flow is all but blocked. It is clear that highway parking must be stopped or drastically curtailed; the community provides roads for movement and not for standage or storage to the general detriment. The multi-storey garage with modern handling aids can accommodate ten cars on the area taken up by one in the street. As to cost, the answer must surely be that those who make the demand must pay for the facilities. If parking were banned or, where appropriate, charged by meter, there would be the incentive and the enterprise to build the garages. The cost would be high, but this would, in turn, tend to reduce inessential traffic by private car. The longer action is delayed, the more vested interests will protest when action becomes inevitable, and the more it will cost. To garage or park a car in New York costs about £1 per day; in London a figure approaching this may well be necessary, but this is small in comparison with the present economic loss.

When we come to trunk routes, we have had some appreciable improvement of existing roads, the 11 miles Preston by-pass, and the yet to be completed 50 miles

of the first real motorway from London to Birmingham. But in comparison with the railway builders of a hundred years ago, and in relation to the present material wealth of the community, what puny efforts these are! From 1830 to 1850 the average length of new railroutes built in Great Britain was 320 miles a year—built, let us remember, without excavators and bulldozers, without steel, and largely without concrete; built just with pick and shovel, barrow and cart. It is true that those responsible had a sense of urgency and a freedom of action that we now deny ourselves, but how the ghosts of Telford, the Stephensons and Brunel must weep to see our loss of vision, of courage and of vigour. But these great engineers were not just specialists working to instructions; they were at the same time planners, designers, builders and managers. Not least, they were able to take responsibility and to develop the broad view from their early years.

Today, there is no less genius available but, under the complexities of modern life and in deference to the idols of equality and collective responsibility, this genius is too seldom developed and given the opportunity to take individual responsibility. A few weeks ago I went through the new Amsterdam–North Sea Canal—it has the biggest locks in the world—and noted the road underpass provided ahead of future heavy requirements. I thought of all the talk of the Thames barrage, and recalled that we have not opened a Thames tunnel since 1908. Brunel built the first under the most appalling difficulties, and with what enthusiasm he would have built the barrage, as his counterparts could do today.

In the Road Research Laboratory, this country has a first-class organisation for research into road problems. Within its limited resources it is doing sterling work in technical development and in traffic analysis, including the causes of accidents and the methods by which they can be minimised. It is in no small measure due to its work that the gross accident rate today is little higher than it was pre-war, when there were half the number of vehicles and their power and maximum speed were far less. Nonetheless the total cost of accidents is now estimated at some £170 million per annum, to say nothing of the human suffering involved.

It is a striking and regrettable fact that we have no established centre for training high-grade traffic engineers, as is done on a large scale in North America and in some continental countries. The problems of traffic analysis, and its integration with highway planning and design, demand first-class minds with special training, and experience that cannot be got overnight. The supply of such people has to be deliberately organised and created, but as yet many of our authorities seem scarcely aware of the need for such help, or of the benefits they could bring. Because of our close-knit road system—agglomeration would be a better word—and the difficulties stemming from the long history of our towns, the need here is greater than in many other lands; we are at last talking of university schools of traffic engineering, yet we have still to move. When they are set up, it is to be hoped that they will deal with transport as a whole and not with roads alone.

The construction of the London–Birmingham highway promises to be a fine piece of work, carried out at praiseworthy speed. The lesson to be drawn is, surely, that it was planned as one entity, and the responsibility for design and execution was unified—to the credit of the Ministry of Transport. No doubt this was the easier, under the present organisation of highway responsibilities, because it was an entirely new scheme. If so, this is one more pointer to the need for a bold re-casting of the present system, with its multiplicity of authorities and overlaps of responsibility.

Dr. W. H. Glanville, F.R.S., the present head of the Road Research Laboratory, and Dr. R. J. Smeed, in a noteworthy paper, (1) last year summarised many of the factors and problems affecting the roads in Great Britain. They estimate that the average speed of motor vehicles in 1956 was 20 m.p.h. in urban districts and 32 m.p.h. in rural areas. The authors calculate, on a conservative basis, that a

change in these speeds of only 1 m.p.h. would result in a saving (or loss) of £29 million and £7 million respectively per annum. If the value of non-working time is included at the same rate as in this calculation, these savings would be trebled to a total of more than £100 million per annum—and who would admit that his own leisure time was without value? Under light traffic conditions on good roads, the average speed is 25 m.p.h. in built-up areas, and 40 m.p.h. in rural areas. Thus, if these speeds are taken as a not impossible bogy, the calculated savings on an economic basis would be over £200 million per annum *under present conditions.* Allowing for the value of leisure time, the figure would be over £500 million per annum.

The paper points out, further, that the time cost of delay increases at more than twice the rate of increase in the number of vehicles using the roads. Since the latter rate is in excess of 7·0 per cent per annum, the time cost of delay is rising at 14 per cent per annum, apart from any remedial measures that may be taken. While no one would wish to press such calculations too far, they do give a clear idea of the order of the loss (or saving) that the community has to consider when dealing with the road problem.

At this point it may be useful to examine briefly what other countries are doing—some of them with economies far poorer than our own. The following table gives data for 1958 based on a report by the International Road Federation (2).

	All motor vehicles except cycles	Total road expenditure	Expenditure per vehicle	Expenditure per inhabitant	Private (3) cars per 100 inhabitants
	m.	£m.	£	£	1956
Australia	2·38	97	40	10	17
Austria	0·43	39	90	5·6	—
Canada	4·41	382	87	23	20
France	5·20	237	46	5·4	8
W. Germany	4·27	382	89	7·4	4
Great Britain	5·48	136	25	2·7	8
Holland	0·57	19	33	1·7	—
Sweden	0·99	54	55	7·4	10
U.S.A.	68·40	3,540	52	21	33

If we consider motorways in their proper concept as reserved for motor vehicles, having dual carriageways and with access only from two-level flyovers or underpasses, Great Britain will by the year-end have a total of 64 miles. West Germany already has nearly 1,500 miles and plans another 1,300 within ten years at a cost of £2,000 million. In spite of her small size, even Holland has some 200 miles of motorways completed, and France, with a fine system of existing roads by British standards, has plans for more than 1,000 miles. Italy already has an extensive system of motorways and is now extending them in spite of difficulties of terrain and a lack of economic resources that far exceed our own.

No really major bridge has been built in this country for twenty-five years, if we except the replacement of Waterloo Bridge which hardly comes in that category. We are at last moving on road bridges for the Firth of Forth, for the Severn, and, on a lesser scale, the Runcorn–Widnes link, but France has already *opened* the Seine bridge at Tancarville with a span of nearly 2,000 feet. It has a capacity of 20,000 vehicles/day and cost nearly £6 million, but in the first three weeks tolls brought in £37,000. Brunel's remarkable railway bridge at Saltash is 100 years old, and even then he wished to make it a road bridge as well; once again, there is

talk of this link between Devon and Cornwall, but how long will it be before it comes into being?

No less than 60 per cent of British trunk roads now carry traffic in excess of their designed capacity, and the load is growing at about 7 per cent per annum (1). But even so, the crucial limitations to traffic flow lie in the towns rather than on the inter-connecting trunk roads, yet so far it is improvements to the latter that have had priority in time and capital. The future plans that have recently been announced do nothing to improve the balance in this respect. It must be remembered that although the urban average speed is 20 m.p.h., the figure for central London is 10 m.p.h., central Glasgow 8 m.p.h., and Edinburgh 13 m.p.h.

It is true that the rate of increase in London traffic falls well below the national average, due no doubt to the extreme congestion. But it would hardly seem wise to limit traffic growth by making conditions so bad that what now exists can barely move! While other great conurbations like New York and Los Angeles may not have solved their own serious difficulties, they have tackled them with a boldness and vigour that has been absent here. They have dealt with them by major engineering works, often of a most imaginative kind. The civil engineers of this country could do the same, if there were the same clear call to action, the same comprehensive approach, and the same realisation that the work must be done, preferably before, rather than after, the traffic gums up.

Since this paper was commenced, the Ministry of Transport has announced the Government's intention of spending not less than £60 million per annum on major road works, and £6 million per annum on improvements in London (4). While this is a step in the right direction, it must be considered far too small when judged against the sheer needs of the situation and the relative savings to be made. It is clear that our present scale of effort will in fact lead us to increasing loss; this may be hidden in the national balance-sheet, but it is no less real and is something we can no longer afford.

With taxation at present levels there is natural and proper reluctance to provide additional capital from current income, but it is for consideration whether the user of major new facilities should not directly service the capital required. Many other countries charge tolls for motorways, bridges and tunnels, as has been done with success for the Mersey tunnel. Motorists would properly press for the abolition of such charges as soon as the community is rich enough to absorb them. Meanwhile they would have the alternative of the older routes.

Railways

The 1958 Report of the British Transport Commission and the White Paper published in July show what marked progress is now being made on the technical side in re-equipment and modernisation, and managerially in the application of more modern techniques of management such as Work Study. Except to learn for the future, it is fruitless to regret the past and how little was done during the first half of this century, but I cannot forbear to point out that this period coincided with the failure to recruit for the railways more than a handful of well-trained technologists or of university graduates from other disciplines. As late as 1956, the British Transport Commission employed only 1,551 professionally qualified scientists and engineers, or 0·23 per cent of their total employees (5). In comparison, the Coal Board had 0·7 per cent, the Central Electricity Authority 2·9 per cent, and the Atomic Energy Authority 10·9 per cent. The effect of this past attitude to recruitment must be a serious drawback for a long time to come, and must make the work of modernisation slower and more difficult than it should be by modern standards. With a more vigorous technological approach in the past, the size of such an expensive 'crash' programme would have been greatly reduced. One cannot but be aware of the different attitude that has existed and the striking technical advance

that has been made on the Continent—particularly in France—and in America. In these countries, university-trained engineers have not only been recruited in greater measure, but many of them have been used on the managerial and operating sides up to the highest levels, as well as on design, construction and maintenance.

We can sympathise with railway managements everywhere on their competitive difficulties in face of both road and air transport. Nevertheless, it cannot seriously be argued that we could do without the railways for our heavy freight and much of our passenger traffic. As engineers we can appreciate, too, the great difficulties of track modernisation while the lines have to be kept in regular use. The question is, are we moving fast enough with existing schemes, and are we even yet thinking with sufficient boldness in the technical sphere? It is true that we have at long last decided to abolish the steam locomotive and to order no more, but already by 1947 98 per cent of all main line locos being built for the U.S. Railways were diesel electric. From the start of the railways until a few years ago we clung, after everyone else, to the chaired bull head rail, though the raison d'etre—that it could be reversed when worn—was quickly found to be unsound. Now the continuously welded rail has been proven, and has real advantages in smooth riding and reduction of wear and tear, but here also we are behind others in rapidly following it up; France, for example, already had 1,000 miles of such track by 1955. This type of rail is best used with concrete sleepers, but this should also be to our advantage, for concrete is indigenous and permanent, while timber is not. Then again, we have only recently accepted the policy of mechanical brakes for all wagons, long after this was standard practice abroad; in doing so, we have kept to vacuum brakes, although pressure-operated brakes have much to commend them from the technical angle and are normal elsewhere. I quote these examples not in any spirit of recrimination for past mistakes, for which we all carry a share of responsibility, nor in criticism of those presently in charge, but to disarm those who always advance objections to any change, to encourage support for the Transport Commission in their present efforts, and to appeal for still bolder policies in the future. What has to be done requires the active help and support of the 'users' in addition to the steps that the Commission are taking. The users must be prepared where necessary to change their own methods and equipment so that the full potential benefits may be obtained. In this it would seem that the Commission, and indeed the Government behind them, must give a clearer lead at the highest level if results are to be achieved in reasonable time.

I would mention a few points that seem to be of particular importance in relation to the crucial problem of road competition, especially for freight traffic.

Figures recently published show that for the total ton-miles of inland transport in 1952, the railways carried 54 per cent and the roads 46 per cent; in 1958, the position was more than reversed, for in that year the railways carried only 44 per cent (6). The obvious reasons for this change are cost, convenience in door-to-door service, and usually in speed. On the last point, the Railway Regions are developing express freight trains and scheduled freight working, and in 1958 35 per cent of freight train mileage was in brake-fitted trains, against 29 per cent in 1957 (7). Although most of these trains ran to stated timetables, by contrast more than 80 per cent of German freight trains work to published schedules, irrespective of the traffic offering. But it is in effective use of wagons that British Railways has the greatest leeway to make up. A broad guide to usage efficiency is given by dividing the total number of loaded wagon despatches per annum into the total number of wagon-days in the year. On this basis, the average time of wagon turnround in 1957 was (8):

Great Britain	12·9 days
France	9·4 ,,
West Germany	5·5 ,,

In 1958, British Railways owned some 1·06 million freight vehicles, and the total distance run (loaded and empty) was 3,505 million miles (7). Thus, on average, each British wagon ran less than 3,500 miles in the year, or roughly 10 miles/day. For expensive vehicles to achieve a functional speed of well under ½ mile/hour is not impressive. If 'C' licence road vehicles were similarly used, there would be few of them indeed! In fact, those over 5 tons average 26,000 miles per annum, or more than seven times as much as rail wagons, in spite of the hauls being shorter.

Of course, much of a wagon's time is spent at the loading and unloading points, often outside the railway's control, but that is where the policy on demurrage charges needs to be bold, not least in the long-term interests of the users themselves. If valuable mobile storage is required, it must be paid for, but quicker turnround would do much to reduce basic rates.

If average turnround were brought down to even six days—and what other countries with similar economies can do should be possible here—the total number of wagons might be reduced to under 500,000, with a tremendous saving in overhead charges, in operating costs, and in the fitting of brakes to existing wagons. It must be noted that the German results stem not only from action by the railways but also from a much more active technical and managerial approach by German industry. It was good to see that in 1958 the wagons in use declined by over 100,000, but the present target of 750,000 wagons in 1963 (9) still seems unduly high.

But there is a further important matter in the size of standard wagons for bulk loads, such as coal, minerals, heavy chemicals, etc. Such traffic represents over 70 per cent of the tonnage handled, but the average wagon load is only 12–13 tons. Other countries have larger standard wagons and carry heavier unit loads, e.g. in Germany the average wagon capacity is 21 tons, as against our figure of 15. While some small wagons are desirable, there must be something peculiar in the British atmosphere—physical or mental—if wagons larger than the present standard of 16 tons, or even the tentative 20/21 ton type, could not be used with great advantage for traffic of this kind. The gain would not be just to British Railways, but to the larger users also, once their sidings were equipped to handle them. Of course, the full implementation of such a plan would take time, and would involve the use of bogie wagons, but unless the policy with regard to future *maximum* dimensions and capacity is fixed and *declared*, there will always be the plea, as from the Coal Board, that the despatchers or receivers cannot take larger wagons with their existing facilities. Clearly our loading gauge prevents the possibility of the 80 or 100 ton monsters in use in North America, but a 35–45 ton load might ultimately well be used for at least 50 per cent by weight of all freight traffic. I know of a case where 40-ton (roller bearing) bogie wagons have long been in regular use, handling up to 1½ million tons of limestone per annum on a round trip of 72 miles, with an achieved annual average fleet turnround from loading to reloading of 32 hours. In this case, the user was both despatcher and receiver, and has gained great benefit from this service in comparison with the former use of small wagons and normal methods. The steel industry is doing much along similar lines with great success, because it, also, is often both despatcher and receiver, and because it has the technical competence and resources to tackle such problems in a big way. But can the same be said of coal, where until the recent development of competition from other fuels, the producer had no interest in transport beyond getting the product away from the pithead?

Unless the railways take advantage of their unique *potential* for heavy unit loads and regular service, their decline will continue. They are making valiant efforts, but, in my view, still have their sights too low with regard to size and turnround, and to stimulating corresponding action by those who despatch and receive. It is ironic that at this time of decline in the coal trade, the first mechanical unit for handling domestic coal should have recently been opened in London. In the

U.S.A., such installations have been common for many decades, one might almost say invariable, in every centre using coal in any quantity.

Where freight cannot go through private sidings, recent developments of containers show great possibilities; to this the Transport Commission is fully alive, but here again, there seems less drive for a national approach on standards and for co-operative working, than is evident elsewhere, particularly in the U.S.A. There the railways face still greater competition, but even so they have survived without State aid. It is certain that they have only been able to do so by the utmost vigour of technical and organisational development. But, of course, they have long regarded rail transport primarily as a matter of engineering, whereas we ceased to do so nearly a hundred years ago, once our rail system had been completed; we are now only just getting back to that idea. I use the word 'engineering' in the widest sense to include the scientific analysis and development of traffic schedules, no less than the investigation of a bridging problem, whether in its general concept or detailed stressing. Both demand the same type of mind, similar analytic methods of approach, and even some of the 'tools' to be used, such as computers, are similar if not actually the same.

Wages and salaries account for some two-thirds of all railway costs, thus the effective output per person employed is a crucial test of productive efficiency. Measurement of 'productivity' is beset by many difficulties, and absolute comparisons can be misleading and unfair. Nevertheless, the objections do not apply so strongly to a broad comparison of trends, if a reasonable yardstick of output can be found. The units of passenger-mile and ton-mile are available and convenient for this purpose. In terms of cost they are similar and do not fluctuate rapidly from year to year; thus, their totals can be added and divided by the total manpower to give a broad *relative* measure of progress over a period of years.

	Passenger-miles plus Ton-miles per employee (10)		
	British Railways	*French SNCF*	*West Germany*
1938	$6{\cdot}6\times10^4$	—	—
1949	6·9 „	$8{\cdot}1\times10^4$	$8{\cdot}9\times10^4$
1950	7·0 „	9·2 „	9·2 „
1951	7·3 „	10·7 „	10·1 „
1952	7·2 „	11·0 „	10·1 „
1953	7·3 „	10·2 „	10·1 „
1954	7·4 „	11·0 „	11·2 „
1955	7·4 „	12·5 „	11·3 „
1956	7·5 „	13·7 „	11·7 „
1957	7·6 „	14·4 „	11·7 „

These figures must not be pressed too far, but the disparity is great, not least in regard to the long-term rate of improvement achieved. The destruction of the French railway system during the war gave the opportunity there for bold developments and striking results as shown by the above table. As the technical work of modernisation becomes effective, we shall certainly see a rapid rate of advance by British Railways. It must never be forgotten that our present difficulties largely exist because for many years capital on a proper scale was not available to the railways; before nationalisation, owing to the enforced system of rates and charges, and more recently, as a result of the Government's economic policy. Now that action has been started, there must be no hesitation in driving it through.

Marine Transport

On the marine side, this country has much to be proud of in its past achievements, but here also technical change is pressing hard on our heels in ship design, in constructional methods, and in port operation.

How many people in this country know of the technical developments that have made Rotterdam the world's second port after New York, and realise the huge industrial development with which it is linked? Tonnage handled in Rotterdam has risen from 42 million in 1938 to 74 million in 1957, whereas London in that period has gone from 41 million to 56 million. If Rotterdam has geographical advantages over London, that should be a spur for us to ensure the most up-to-date technical development and to re-examine our attitudes and operating methods, such as the present cumbrous dock management system and our old (or new) restrictive practices.

As a student working in a shipyard my first job was to mark off a bronze casting for a skylight opening gear; it was a 'special' with its own drawing and pattern. On asking why equipment of this kind was not standardised, I was told that every line (and sometimes every ship) had its own particular designs—perhaps fads and fancies would be a better description. No doubt there has been some advance since then, but the high speed and low cost of ship construction in many foreign yards makes it pertinent to ask whether, as between owners and builders, we are yet doing all that we might to develop dimensional and other standards wherever possible. The traditional skills and quality of British shipbuilding are unrivalled, but that does not detract from the need for an increase in the application of scientific engineering and the employment of more highly qualified technologists who will be essential if the industry is to keep its place in the international race.

The reciprocating steam engine was quickly applied to shipbuilding and another British invention, the Parsons turbine, was immediately developed by him for that purpose. The diesel engine was not a British concept, but our marine engineers were not slow to adopt it. Now we are faced with a new and challenging method of propulsion in nuclear energy. On land, the Atomic Energy Authority, the Central Electricity Authority and the Electrical Industry have pioneered with success owing to their great concentration of technical strength. On the sea, where in the past we have led, we are hesitating while others show the way. I do not underestimate the difficulties, the cost and—as at present envisaged—the limitations of nuclear power for marine work. But can anyone doubt that it has a very great future, or that this is the type of development where knowledge is best bought the hard way, rather than by following others and having to pay tribute to them in money and prestige?

The theoretical advantage of submarine transport in the deep and open sea is undoubted, but the problem of navigational hazard and of handling in shoal water and in port are formidable. I would think they are unlikely to be solved in a satisfactory and economic way for a long time ahead, except perhaps for small and very special uses. Nevertheless the idea is stimulating, and a refreshing break-out from conventional thought, So, too, is the 'Hovercraft', though whether this is to be regarded primarily as ship, aircraft, or land vehicle, is far from clear. If it does prove successful, its most obvious use is as a ferry in (relatively) narrow waters.

Air Travel

On the air side, it is interesting to note that no end to technological advance is yet in sight after fifty years of rapid change. In large measure this is due, no doubt, to the physical conditions of three-dimensional travel, but I believe there are two other factors that greatly affect the position. In this field, unlike land transport, engineering science has always been recognised as the essential basis for progress; the horse, so to speak, came out of science by engineering and is ridden by

technology. In the second place, the air side, both civil and military, compels international comparison and rivalry. If British Railways had operated in France and the S.N.C.F. over here, in competition with each other, what faster progress we might have seen!

The 'Bleriot' London–Paris air race has underlined a fact known to all who use air travel—the time taken in connecting town centres with the start and ending of a flight. This earthbound movement often exceeds the flying time, and with jet aircraft it is becoming no small factor even in long distance travel. It would seem that the solution must lie in some form of vertical take-off and descent, whether of helicopters providing a feeder service to runway-launched planes, or more radically in long-distance aircraft capable of vertical take-off. But any such machines will still require landing and parking space on no small scale *within* large towns, if the basic difficulty is to be overcome. Here is an almost certain requirement of a major kind, which appears to demand far more attention than it has yet received, for it is close upon us. As in the case of urban roads, the longer it is left the more it will cost. It should surely be possible for the planners to see that other developments do not sterilise potential sites convenient for this purpose.

I cannot forbear a personal opinion on the possibilities of ballistic flight with which I became involved from 1943 onwards. I never had any doubt about the immense potential importance of guided rocket missiles in the military sphere. I am equally convinced that they will play no appreciable role in civil transport for the next hundred years, at least. Earth satellites as radio relay stations, or for meteorology, may be worth while, but if a human being lands on the moon and *comes back* alive before 2,000 A.D. I should be surprised. Of course, the probing of our universe is of great scientific interest, but it seems to me that this is likely to be one of the most unrewarding fields of research as far as any possible practical benefits are concerned. The military work on missile development has led to some technical advances in electronics, servo-mechanisms, and metallurgy; it is only too likely that such work will continue and there would, therefore, seem the less need to pursue work of this nature for purely civil purposes. It would appear that there is something wrong with our sense of values and with our research priorities if we contemplate the same order of expenditure on the investigation of outer space as currently on road research!

Conclusion

It is natural to compare a national community in its development and functions to the human organism. The analogy is close, whether one considers the early stages of growth with its increasing complexity and the rise of consciousness, or compares the muscular system of the individual with the industrial sources of power. Transport clearly corresponds to the circulation of the blood, as we recognise when speaking of 'arterial' roads; similarly, the body's nervous system has its counterpart in 'communications', if that word is used in its fuller meaning. How far human ageing and death is normally due to loss of tone in the circulatory system it is for the medical scientists to say, but even the layman knows that arterio-sclerosis and thrombosis are deadly dangers; so, too, are the corresponding diseases of transport. But here there is indeed a difference between the human and the corporate body. The latter has it within its own power to renew and develop its transport systems indefinitely to ensure healthy existence and, if desirable, growth to the limits of geographic space.

Since the last war we have done much to extend our industrial resources for the production, as it were, of new tissue and increased blood supply for the body politic. My argument is that the development of our land transport system has, relatively, fallen far short of our needs. In consequence, the whole body suffers a

loss of tone and efficiency. This is a condition we cannot afford in a competitive world, and one that we should not tolerate for the sake of our pride or our comfort. We must redress the balance by far more capital development, particularly of the road system, and by training a greater proportion of our best minds in the understanding and use of science for this as for other purposes.

REFERENCES

(1) 'The Basic Requirements for the Roads of Great Britain', W. H. Glanville and R. J. Smeed. *Proceedings of the Conference on the Highway Needs of Great Britain 1957*. Institution of Civil Engineers. London. 1958.
(2) *Highway Expenditures, Road and Motor Vehicle Statistics for 1958*. International Road Federation. London, Washington, Paris. (undated.)
(3) *Basic Road Statistics 1958*. British Road Federation. (Quoted from *National Provincial Bank Review*, May, 1958.)
(4) *Report of the Committee on London Roads*. London. H.M.S.O. 1959. Cmnd. 812.
(5) *Scientific and Engineering Manpower in Great Britain*. London. H.M.S.O. 1956.
(6) *The Transport of Goods by Road*. London. H.M.S.O. 1959.
(7) *British Transport Commission. Annual Report and Accounts 1958*. London. H.M.S.O. 1959.
(8) *Annual Bulletin of Transport Statistics for Europe 1957*. United Nations, Geneva. 1958.
(9) *British Transport Commission. Re-appraisal of the Plan for the Modernisation and Re-equipment of British Railways*. London. H.M.S.O. 1959. (Cmd. 813.)
(10) Based on information from Annual Bulletins of Transport Statistics for Europe, United Nations, and British Transport Commission. Annual Reports and Accounts.

THE NATURE AND SCOPE OF ARCHAEOLOGY[1]

ADDRESS BY PROFESSOR IAN A. RICHMOND, C.B.E., F.B.A.

PRESIDENT OF SECTION H

THE early inclusion of archaeology among those scientific studies which are considered to be advanced, or at least to be open to advancement, by the British Association is a significant tribute. It indicates the important contribution which archaeology so soon began to make to the triumphal progress of geological studies, in their bearing upon the antiquity and evolution of mankind. It connotes the moment when a new method in the study of antiquity was introduced by the recording of stratified objects which corresponded with varying degrees of precision to the fossils of the geologist, and, like them, introduced typological dating or, less often, absolute dating through objects bearing their own date superscribed or marked. It marks, too, the inception of a new phase of palaeontology, wherein the study of primeval man passed into remoter time, back beyond the recognisable advent of man the tool-maker, into the epoch of the earliest anthropoids, whose instinct and cunning lay under very little obligation to intellect, while our own understanding of them depended upon objective anatomical consideration. It was a cold and somewhat inhuman field, frigidly and rigidly scientific, in which the observed phenomena offered few problems to the objective and skilled observer and few opportunities to subjective speculation. But this distant realm of scientific observation lies beyond or behind the ken of archaeology. For the subject of archaeological study is not man himself, whether refined or raw: that is the province of the anatomist, the physiologist or the philosopher. Nor is archaeology concerned immediately with man's behaviourism, social and political: for that is the affair of the anthropologist, the sociologist or the historian. The true subjects of archaeological study are the objects that man makes, whether this be tools or utensils, plain and decorated, fields or earthworks, simple and complicated, structures or buildings, small and great, modest and splendid, ornamental and utilitarian. They embrace in particular representational art, not excluding any of its forms: for this in its unending variation is one of the least distorting mirrors of man, however strange and misshapen a creature it may reflect. Again, forms of art contitute an invaluable basis of classification and are in themselves a medium of exchange in the diffusion of culture so vivid and so varied as to become veritable tracer elements indicative of the varied relationships between and within communities and peoples.

In no field has the impact of archaeology been more impressive or more appealing to the imagination than in prehistory, wherein, as the very name of this aspect of antiquity suggests, it forms virtually the sole basis for the study of ancient man. Through prehistoric studies the field has not only extended to cover almost every portion of the globe; but the time represented by its earliest recognised manifestations has continued to recede until its actual definition has become dim indeed in terms of normal reckoning. Hence the possibilities of radioactivity, tree-ring cycles, and terrestrial magnetism are now being explored, and with fruitful promise, for what they can offer in fixing remoter chronology. And because the products of prehistoric man most impervious to destruction happen to be flints and pottery,

[1] Address delivered to Section H (Anthropology) on September 7, 1959, at the York Meeting of the British Association.

immense effort has been expended in the study and classification of these rewarding artefacts. No less impressive, however, is the progress more recently made in excavation and understanding of prehistoric timber-work, whether this be structures in tombs or in buildings for use by the living for worship or habitation. These developments have brought about a new understanding of primitive man, far outstripping anything considered possible a generation ago. Again, the systematic study and laboratory examination of durable metal objects—one may cite in particular the spectrographic studies now in their first youth—are contributing enormously to a real comprehension of ancient man's technical capacity and to his commercial activity in the trafficking of such articles or in the acquisition of the raw materials from which to make them. It is not, however, surprising that the outstanding characteristic of the over-all picture of prehistoric man should be its very great unevenness of definition and perspective. Resources, cultural achievement and advancement differ so widely in different regions that the story tends to become not that of the effect made by man upon his environment, but, contrariwise, that of the effect of his environment upon man. The part played by nature through the quality of soils and the vagaries of climate is increasingly perceived to be of the greatest moment and is the more important according as man is the more primitive in his equipment of tools or in his knowledge of how to make and use them. Among natural resources, minerals perhaps have the most obvious and certainly the oldest place in study. But a no less important position is in fact occupied by the studies of geology, geography, climatology, palaeobotany and podology, from all of which may be extracted particular information upon the type of natural environment in which man found himself and upon the opportunities for exploitation of natural resources at his disposal. These are some of the most striking aspects of the objective side of the picture; but there is a subjective side also. Such specialised skills in research, including some not mentioned here, form a bridge by which the archaeologist can make contact with an unusually large number of fellow-workers in the field of knowledge: indeed he may, wittingly or unwittingly, become himself the bridge that unites them and their widely differing work in a wholly new and veritably unexpected comity of learning. It might perhaps seem in some degree exaggerated to describe archaeology as a new branch of humanism, but it is certainly not to be denied that, exactly in the fashion of the best and most valuable humanistic studies it unites a very large number of widely differing branches of learning. These do not arise from it; they are normally independent lines of inquiry, concerned with totally different branches of knowledge. They are on the other hand highly relevant to archaeology, just because they are capable of contributing something vital to the grand synthesis of knowledge comprised in archaeological study of the works of man.

Our assessment has so far proceeded along the lines which seemed set for it by the inclusion of the subject in this Association's categories of scientific study, and particularly by its relationship not only to geology, but, as has become apparent, to a large number of subjects which technological, statistical or quantitative inquiries have brought into the world of empirical or experimental studies. But the moment has now come to examine some parallel lines of development, which have been set going by the impact of archaeology upon other and older fashions of thought. There is no doubt that one of the most important of the older fields to be affected by the new archaeological method of inquiry was that of antiquarian studies. It is hard here to restrain a smile. The antiquary, vain and inaccurate, self-centred and self-deceiving, far-fetched in theory and preposterous in outlook, has been a favourite subject of jest and scorn, sarcasm and light relief. Sir Walter Scott and Charles Dickens positively consecrated the most mellow of such figures, just as Rowlandson and other caricaturists pilloried the meaner souls among them, whose personal intrigues touched the depths of discredit. All these types die hard:

but the best among them remain a noble band. Leland, Camden or Sir Robert Cotton, Aubrey, Sibbald or Baron Clarke, Drake, Joseph Hunter or Samuel Tuke —to mention *honoris causa* a trio especially linked with York and Yorkshire— Stukeley, Gale or Horsley, Hodgson, Collingwood Bruce or Roach Smith: these were men who adorned their age and society, and who not only advanced the study of antiquity, but systematised it. When archaeology came upon the scene it offered new methods of solving old questions, of which many had long been formulated by earlier antiquaries. For the best kind of British antiquarianism was that founded upon humane studies operating through written sources copious enough to constitute a body of ancient tradition which set its standards by those of the classical world. Thus, if indeed at one remove at least and through agents of varying quality and outlook, British antiquarianism was linked with the mainstream of classical and humanistic tradition.

It is not difficult to see that in some respects this tradition might prove a hindrance or an embarrassment. It was as tempting to the antiquary to force all his known material evidences of ancient culture into the strait-jacket of classical written tradition as it seemed proper to the older theologian to squeeze them into the restricted chronological framework of Archbishop Ussher. But treated with discretion the literary tradition could be less harassing than the chronological: for who, after all, has yet bettered the acute Lucretian statement on the evolution of primitive man? Within the Lucretian theory there was room for all prehistory to grow untrammelled. Lucretius, moreover, successfully avoided the temptation of attaching terms or labels to his definition, a process psychologically so seductive and scientifically so often disastrous. To take only one example, it would be a salutory study to investigate just how much confusion has been introduced into how many fields by misuse of the term Druidical. A second source of embarrassment was the centripetal attraction of the classical world, a trap especially difficult to avoid for those who not only believed that the classics set a standard but knew that they offered a career. The consideration of career is now less predominant. But in the matter of setting standards it will be readily admitted that humanistic standards remain an important part of the stock of tested truth at the disposal of mankind and as such continue relevant and inspiring to successive generations. It must further be added that the broad concepts of knowledge proclaimed by the classical tradition at its highest have never proved hostile to any advance in knowledge so long as this was prudently conceived and employed: all they assert is the highly important principle that pure knowledge is not something to be developed *in vacuo*, as many scientists think, but due weight must be given to its indirect consequences as well as to its immediate potentialities. The impact of archaeology, however, has not accentuated recognised weaknesses in the classical position: for in this field of knowledge, as in others, the function of archaeology has not been to transmute old forms but rather to give them new life by endowing them with new relevance and new content. Yet the richness of such gains has been vastly greater in the world of classical archaeology, just because there happens to exist, giving harmony and significance to the archaeological material, a large body of varied literary and epigraphic tradition, which is the very stuff of thought and outlook and which enables the material to be interpreted not out of modern experience, at two thousand years' remove from the scene of action, but in the light of ancient contemporary comment and assertion. It may indeed be argued, and demonstrated, that this contemporary opinion is often biased; and it is indeed seldom free from predilections. But, however biased it may be, it is at least contemporary bias, not distorted through modern spectacles and not the product of standards of judgment foreign to ancient minds. Indeed, its study can inculcate intellectual lessons of the highest positive value. It will demonstrate, for example, how markedly different may be the outlook of successive generations, and how

foolish and even dangerous it may be to apply the standards of one age to the achievements of another. It will show how contemporary opinions can be manipulated and what strict caution must be applied to assessing not only their face value but their inner meaning or their relevance to the immediate problems of their time. It is thus in no sense a mere knowledge of ancient politics or of ancient thought that is in such studies ultimately valuable, but the incidental training in critical perception and judgment which creates the humanistic outlook, sober and free from illusion, firm in predilection for truth. The reproach has sometimes been levelled against the humanist that he is insufficiently empirical, too closely dependent upon traditional experience and too reluctant to indulge in experiment. But the intellectual outlook which he fosters and embodies is too tough, as well as too precious to be attacked and eroded by half-truths or, better, half untruths of this kind, which are too often asserted by shallow critics who know little or nothing of the discipline required to reach the central position. In these circumstances also the contribution of archaeology has been to strengthen anew the links between humanism and empiricism: and it must be freely and fully recognised that in so doing it is in fact only confirming afresh an attitude of mind implicit in humanism at its most creative and explicit in the birth or rebirth of scientific thought and discovery which it is the peculiar power of humanism to engender or stimulate.

The central place here accorded to the relationship between archaeology and humane thought is of fundamental importance, in as much as it concerns the whole content of our intellectual attitude. Here is a situation in which, quite exceptionally, archaeological discovery and research is linked to a tradition so copious and so well and surely founded that it can comprise within itself, and enunciate, its own terms of objective and subjective thought. Each generation may ask of this body of material, great both in quality and in content, its own questions: but the terms of the answers can and indeed must be cast in their original ancient mould and not in one of modern fashioning. It might be held that the same thing could be done in Egyptology, where there is a copious hieroglyphic and demotic tradition, or in those various civilisations of the East which have furnished an abundant cuneiform documentation. But, rich though such material may seem, in the matter both of plentiful variety and of power in ideological expression there can be no comparison between it and that provided by classical civilisation; and this point is perhaps best illustrated by the fact that, whereas knowledge of these older cultures now depends almost completely upon archaeological discovery, in classical studies archaeology takes second place to literature in mutual dependence. The over-all effect is that the two studies together produce a rich synthesis of a tradition shaped by its own standards and at its best when most clearly expressive of these.

The classical archaeologist does not therefore find himself in the same dilemma as the archaeologist confronted by civilisations or cultures which are more or less completely devoid of any literary tradition. It must be realised that where there is no literary tradition there cannot exist any clear and unambiguous assertion of spiritual values. This must inevitably result in a more materialistic approach to the subject, since in effect only material relics can furnish the scene. The situation is inevitable, but only by reflection upon the loss in understanding of classical culture that would be represented by the absence of classical literary tradition, or the unavoidable mistakes in interpretation that such a situation would produce, does the extent of the difference become apparent. In the light of this how much more self-evident is the need for caution in interpretation and for the clearest possible emphasis upon the distinction between ascertained fact and working hypothesis, or between a deductive or inductive treatment of the questions at issue. This is not to suggest, still less to state, that classical archaeology should monopolise study or even that it should form the first part of any archaeological training, however profitable this might be. It is intended only to underline its central place, at the

position where archaeology and literature meet most vividly and fruitfully, in an atmosphere most congenial to the exercise and development of critical thought. Attention should also be drawn to the ascertained fact of historical experience that in those countries where tyranny has flourished one of the first manifestations of intellectual dictatorship was either the distortion of classical archaeology to serve political propaganda or a flight from it just because the clearly expressed messages of classical culture could not be twisted and distorted to serve other ends. There is no need to stress the obvious embarrassment to tyrannical rule of a classical tradition which records at once so many experiments in tyranny and so many rejections of it, nor the salutary lessons in the use and misuse of liberty which the same tradition manifests. The attitude to classical studies and archaeology can indeed serve as a veritable political barometer: and it may be doubted whether the deeper implications of this matter are realised by those who are unaware of the dynamic power of these studies in the realm of ideas and ideals.

It cannot then be denied that the usefulness of archaeology increases the more closely it can go hand in hand with a lively literary tradition: that is to say, its usefulness in helping to build up a complete picture, in which ancient contemporary ideas illuminate and are illuminated by that culture's material creations. When this ideal cannot be realised, however, archaeology must take the position of the sole medium of information: and it is right to emphasise yet again, in view of the difficulties that may beset an appreciation of the situation even when supplied with the maximum amount of circumstantial information, how much caution is demanded and how heavy a responsibility attaches to the interpretation of the results. For the material results themselves have been seen in our time to lie open to misinterpretation in the service of political ends; whereas their value and lasting worth must depend upon complete integrity of mind and freedom from political bias. It may be noted that experience has now shown that a preoccupation with cultures so remote and so barbarous as to have no connexion with any records of thought and feeling contemporary with themselves may accompany modern tyranny of the grimmest kind and can even be employed to subserve its ends or misrepresented as an endorsement of its terms. Hence, the more remote the culture, the heavier and the more delicate the task of assessing its meaning. Further, the best training and the best standards in archaeological interpretation are provided by the classical field, which can stand for a pattern in such matters: not because it is less difficult, but because the difficulty here consists in harmonising the richness of the material and the abundant variety of evidence concerning contemporary reactions of mind. He who knows these difficulties best will in turn best appreciate the unseen hazards of judgment in a field where paucity or total lack of evidence upon contemporary thought is the outstanding weakness. He who desires adventure will indeed find his fill, but he will venture best who is best disciplined in critical power applied to himself and his subject.

These conclusions imply the plain necessity to the archaeologist of the widest and deepest acquaintance possible with every kind of material which may contribute to his background knowledge. But they in no fashion excuse him from competence in the techniques of his own subject. There has been an observable tendency on the part of some performers in the field to conclude that many of the essential techniques, such as photography or surveying or drawing of sections can somehow be delegated or that the responsibility for their execution can in some way be divided. This is highly difficult in practice and its consequences may be dangerous. It may be pertinently asked whether anyone ever really looks at a complicated section in full except by drawing it; or whether the right photograph can be secured, especially in the British climate, at the right moment except by the worker on the spot; or whether a good survey can really be prepared and executed by an extraneous personality. There are indeed some exceptions, though not many, which

prove the rule: but, as published reports will show, there are some dismal blanks or sorry disasters to illustrate the consequences of neglect. The more technical ability a professional archaeologist can himself master, the better can he meet the inevitable emergency and the deeper understanding will he achieve of his material, its ordering and presentation.

The plea which has here and now been made for breadth of vision and for precision in method and for the best things in the humanist outlook as the best inspiration of the attainment of both, might well seem an encouragement to those who have watched the various constituent studies of Section H grow until each within themselves might fitly claim to constitute either a section or at least a predominant sub-section. Indeed, this is a difficulty from which few sections within the British Association are free. It could be argued with some force that archaeological method, reinforced by so large a number of ancillaries and co-partners drawn from so many different fields, might itself constitute a worthy and reputable section, which would undoubtedly be assured of wide popular support. But what of those disciplines which have also grown up in this Section from earlier days, if not from its very beginning, that is, the majestic trio of ethnology, anthropology and folk-lore? They, too, have their claims for time and attention, claims which often seem to jostle one another in our programme. The relation of these to archaeology is more like that of distant cousins, in the various meanings which that adjective may hold. But the effect of the steady widening of archaeology in scope and its lengthening in time, cannot be held to have had an adverse effect upon the relationship. Paradoxical though this may seem, the changing circumstances might be deemed to have brought them closer together, in the sense that all of them potentially hold more for archaeology than they have done before. All of the material has relevance by way of analogy. The ethnologist, primarily concerned with racial cultures and habits among the wilder peoples of the earth, is normally following or recording primitive cultures which survive or are at least not yet extinct. Many of the materials and habits and objects with which he deals are so perishable that in the archaeological world they rarely survive unless the dessication of Turkestan or the ice and snow of Greenland or the Altai have preserved them. But when such a collection as Sir Aurel Stein or Rudenko have made is recorded, it becomes vividly clear how little separates the work of the ethnologist and the archaeologist and how analogy from the one may evoke explanation and understanding in the other. There are fields which require more exploitation in common than either side has normally time or opportunity to develop. It is a region in which our distinguished speaker Professor Grahame Clark has done much work, and nothing could better illustrate how profitable it might be than his brilliant studies of ancient and primitive technical methods.

The anthropologist may seem to have less to offer to the common weal. Perhaps the chief lesson to be learnt from him comes close to that which Aristotle's *Politics* have to teach; of the unending variation and ingenuity evinced by man in devising social relationships, either in family or community. Anthropology however has its own story to tell of the intimate relationship between these organisations and religious belief or economic needs. But such material is gathered only at the cost of very great patience and effort in understanding, and with the same meticulous attention to detail as the archaeologist aims to devote to his own particular objects of study. And when it is realised how much of meaning and importance may be implicit in a comparatively innocent material manifestation which an archaeologist, in default of the anthropological explanation, would be compelled to interpret at face value, exactly the same lesson is learnt as literature might teach, always excepting the fact that literature is not analogy but contemporary record. At the same time the expansion of anthropological work offers an increasing wealth of analogy and variety upon which to draw. Here, too, that side of the discipline

which is concerned with the human body has its own increasingly valuable contribution to make. The anatomical and anthropometrical details, the studies of bone structure and of the osteological effects of disease, the significant odontological information derived from improved study and understanding of the teeth, are proving of the greatest value. There is need for much more interchange of actual skeletal material, particularly of groups of such material, and for the systematic organisation of its study in relation to archaeology. The archaeologist is perhaps prone here to overlook the possibilities of his material; and there is an excellent example of work here undertaken in York at the Romano-British cemetery in Trentholme Drive. It may be felt indeed that in this sphere there is room for more specific organisation of scientific study towards these joint ends, and that an Institute devoted to the purpose might be of value to both sides. Blood-group tests are another form of inquiry which might seem worth further exploitation, especially in those areas where national or tribal groups are known to have been settled. For example, has any comparison ever been developed between the Marne and East Yorkshire or Hertfordshire, to take a simple example of known tribal connexions susceptible of a test. In short, to return to the main contention, it is not necessary to suppose that as knowledge widens disciplines fall further apart; widening knowledge may well be the amalgam which brings them together again, often in quite unpredictable combination.

The specialists in folk-lore belong to yet another group of students connected with the survival of ancient belief and social habit or practice. An example which sticks in the memory is the rhyme quoted long ago by Sir Mortimer Wheeler in his account of a cremation burial connected with the world of the living by a pipe for libations or further deposits of ashes. In a strange and eerie fashion the language and thought of a later age mirrors, and is itself illumined by, the custom of an earlier epoch, the connexion between them becoming evident only when the one is focused upon the other. The old rural world of these islands was and yet is full of such things. The peculiar difficulty in this field, however, is not the collection of such traditions, in which only accuracy is required, but their evaluation. Some expositors of such matters take their place with the pyramid-prophets, the alinement-fanciers or the misinterpreters of *lusus naturae* in the grand and solemn procession of British quacks, whose conviction is matched only by their effrontery and their power of variation upon the undistributed middle. Such people live a charmed existence in the realms where angels fear to tread, but they have no standing where science or humanity reign. To purge such elements should be the first concern of those who care for the reputation of the subject, and when this is done a vastly interesting and curious stock of tradition remains. Much of it lies in the region where archaeology, anthropology and literature meet, and it enshrines material of value to all three. It is therefore impossible to regard folk-lore as irrelevant, and this is after all the humanist creed; *homo sum et nihil humani a me alienum puto*: a healthy and an earthy creed, shot with as much of that idealism as may link us in the common hunt for truth, in the common need to preserve liberty of thought and in a common desire to express that liberty with charity, clarity and honesty.

ARTIFICIAL ORGANS: BIOLOGICAL APPLICATIONS[1]

ADDRESS BY PROFESSOR A. HEMINGWAY

PRESIDENT OF SECTION I

Introduction

THE WORK of Sidney Ringer in the early 1880's can be taken as a convenient, if a somewhat remote and arbitrary point at which to initiate the discussions which are going to occupy the next two sessions. During these years Ringer showed that the properties of living tissues, as exemplified by the frog heart, could be investigated provided the tissue was maintained in a fluid environment which was not only isotonic but also contained the cations sodium, potassium and calcium in certain concentrations and proportions. And, more particularly, he demonstrated that the functions of the organ were powerfully influenced by its ionic environment. Provision was made also, although empirically, for the establishment of a reasonable pH and a buffer system against acidity by the addition of sodium bicarbonate. Later, Locke modified the composition of Ringer's solution to make it suitable for mammalian tissues and showed that the addition of glucose to Ringer's solution conferred important nutritive properties on the solution. Tyrode, Clarke, Dale, Krebs and others added traces of other cations, or modified slightly the concentrations given originally by Ringer, to provide solutions which seemed to give greater viability according to the particular species and tissues with which they were working.

Although the provision of an artificial fluid, practically a tissue fluid, in which isolated tissues could survive was an early necessity for the development of experimental physiology this is now taken for granted and it would be interesting to know how many of the biochemists, for instance, the world over who daily investigate intracellular biochemical reactions in tissue slices or in cell suspensions pay a thought to the history of their supporting medium beyond referring to it as Krebs phosphate or Krebs bicarbonate buffer.

Isolated Tissues

Thin portions of isolated tissues, particularly those having a low metabolic rate, such as stomach, intestine, uterus and blood vessels will continue to exhibit their intrinsic activity and to respond to drugs for many hours if they are suspended in a bath of oxygenated Ringer's solution. Tissues or slices of organs (e.g. liver, kidney) which have a higher metabolic rate or which, like striated muscle or nerve can be activated repetitively by electrical stimulation will survive for long periods if their thickness (or rather their thinness) permits oxygen to reach the interior of the tissues by diffusion. A vast amount of assaying of pharmacological substances for both research and industrial production is undertaken on preparations of isolated tissues.

Other methods for maintaining tissues in a surviving condition employ superfusion and perfusion to keep the cells of the tissue in a suitable environment. When the former technique is employed a piece of tissue is suspended in air and kept in

[1] Address delivered to Section I (Physiology and Biochemistry) on September 7, 1959, at the York Meeting of the British Association.

good condition by a stream of a suitable solution running over it. The stream can be stopped and the action of drugs in concentrations as low as 10^{-9}, in some cases, can be tested by direct application of solutions of them to the tissue.

While superfusion—the running of fluid over the tissue—is a relatively new technique, perfusion—running fluid under controlled conditions through the blood vessels of a tissue—is one of the oldest employed in the investigation of the properties of isolated tissues. Its use has led to many important discoveries but the perfusion of isolated organs or tissues with Ringer's fluid or one of its modifications, is usually possible for only a limited period before they become oedematous. In normal circumstances there is an interchange between the blood and the tissue fluid as blood flows through the capillaries. In the conventional view the pressure at the arterial end of the capillaries is about 35 mm Hg and at the venous end 10. The walls of the capillaries are permeable to water and crystalloids which will pass through under the influence of this hydrostatic head. But the proteins of the plasma to which the capillary wall is almost impermeable will modify the rate of filtration of water and crystalloids because of the osmotic effects which the proteins produce. The view is usually taken that although fluid passes from the blood into the tissue fluid at the arterial end of the capillary, a portion of this passes back at the venous end of the capillary while the remainder makes a more indirect return to the blood stream through the lymphatic system. Attempts to convert Ringer's fluid into artificial blood must meet this difficulty.

In medical practice it is frequently necessary to replace fluid which has been lost from the body. This may occur after prolonged vomiting or diarrhoea where the loss may be regarded as water and electrolyte loss as a whole; or the loss may be more particularly from the vascular bed as in haemorrhage or following severe burns. Intravenous infusion of fluid is an obvious treatment for these conditions. For the treatment of dehydration the infusion of isotonic solutions of sodium chloride or glucose which can pass through the capillary walls into the tissue spaces is usually sufficient. But if blood is to be replaced it must be with something thicker than water; the fluid must contain large molecules which, because they are able to exert osmotic effects, will keep the fluid inside the vessels. Transfusion of blood is the obvious answer but in many cases the infusion of a non-toxic and non-reactive solution which would 'expand' the existing blood volume would be sufficient and the demand on blood transfusion services would be reduced. A straightforward way is to freeze-dry plasma or serum. The product can be stored for at least ten years and the plasma reconstituted by adding sterile pyrogen free water. Attempts have frequently been made, however, to convert Ringer's solution into artificial blood by adding to it substances which would exert an osmotic force when the solution was infused into blood vessels. Gum acacia, isinglass, pectin are examples of the additions which have been tried but have all been discarded in turn partly because of the difficulty of standardising the size of the molecules but also because they showed long term toxic effects. Foreign proteins such as ox albumin cannot be used because of the development of sensitisation phenomena.

Recently, techniques for producing dextrans of a suitable molecular size for intravascular infusions have been evolved. They involve the microbiological polymerisation of glucose derived from sucrose. In the native state the dextrans consist of about 200,000 glucose units forming macromolecules with a molecular weight of 40 millions. For transfusion the natural molecule can be reduced in size by partial hydrolysis followed by repeated fractional precipitation so that a range of molecules with an average weight of 76,000 is produced. In a 6 per cent concentration they exert about the same osmotic pressure as the plasma proteins and appear to be non-toxic. The possibility that dextrans may have clinical antigenic properties is not finally ruled out but at the moment the introduction of this material seems to offer the nearest approach to an artificial plasma which has been achieved.

No significant progress has been made in the production of solutions which can carry oxygen in easily reversible combination. Solutions of haemoglobin are useless because the haemoglobin molecules are small enough to be filtered off in the kidney where they can block the kidney tubules and prevent the formation of urine.

The Artificial Kidney

Rather more than forty years ago, Abel, Rowntree and Turner (1914) were able to demonstrate that diffusible constituents could be exchanged during life across a membrane separating blood and a watery solution. Blood, rendered incoagulable by hirudin obtained from leeches, was passed through several feet of collodion tubing immersed in Ringer's fluid. It was shown that, for instance, amino acids could be separated from the blood stream by dialysis. It was suggested that while this method of removing substances from blood could not be made completely specific for particular substances it might become the basis of a technique for undertaking some of the functions of the kidney during a period of temporary renal failure and the authors actually referred to the apparatus as an artificial kidney.

After a few abortive attempts by other workers, Kolff in 1944 modified Abel's original design. He had the advantage of heparin as an anticoagulant, cellophane tubing as a dialysing membrane and a mechanical method for keeping solution flowing across the surface of the membrane. In Kolff's apparatus 30 m. of cellophane tubing, 25 mm. diameter, giving an area of about 2 m^2 was wound spirally on a metal frame which rotated slowly in a bath holding a solution of NaCl, KCl, $NaHCO_3$ and glucose in water. The ends of the cellophane tubing were attached to rotating couplings through which connection was made to an artery and a vein and blood flowed steadily through the cellophane tube. In the first trials of the apparatus several grams of urea and other substances were removed from the blood of patients suffering from renal diseases. In its latest form the apparatus has been modified only slightly from the original, although in one development of it the coil has been made more compact and is held stationary while the bathing fluid is circulated. There seems to be the disadvantage that the blood may not be exposed as uniformly on the membrane as with the rotating coil type. The 'artificial kidney' acts only because of differences in concentration of constituents on the two sides of the membrane, but, in addition to the concentration gradient, differences in rates of diffusion may affect the movement of one constituent relative to another. Nevertheless, the concentration of substances in the blood can be regulated by the operator through control of the concentration of individual constituents of the bathing fluid.

The artificial kidney is but a shadow of the living kidney. It is true that the first step in the formation of urine in the mammalian kidney is the blind formation of a proteinless filtrate from the plasma. To do this the human kidneys are provided with between one-third and one-quarter of the total blood volume per minute and in the course of a day the volume of filtrate formed is nearly forty times that of the blood. From this 'veritable Niagara of fluid', as Homer Smith terms it, the renal tubules reabsorb some 99 per cent of the water, usually all of the glucose and the major portion of the sodium chloride. Other substances remain behind to be excreted in a much higher concentration than in the blood, and, in addition, the tubule cells are able to secrete some actively. In the course of these operations the kidney is able to modify the composition of the urine, partly by a process of auto-regulation, partly in response to the influence of hormones circulating in the blood, with the result that the composition of the plasma and the tissue fluid varies only slightly. In renal disease the kidney loses part, or the whole, of this regulative faculty; in extreme cases the production of urine stops altogether. As a consequence, the chemical composition of the tissue fluid may drift so far outside

its usual range that it hinders or prohibits the activities of cells and tissues. Sometimes the causes of the disease are temporary and the pathological changes are reversible. The clinical problem is whether the individual can survive the period during which the chemical composition of the blood and the tissue fluid is deranged. In such circumstances the artificial kidney can be used to correct and restore the composition of the blood until the real kidneys recover their functions. Therefore, except as a palliative, its use in clinical work is likely to be limited to the treatment of conditions which are reversible. Occasionally it might be used to assist in the rapid clearance of some toxic substance, e.g. barbiturate from the blood.

The sucessful use of these machines depends upon a team composed of doctors, biochemists, nurses and technicians and only frequent employment of the team and the apparatus leads to efficiency in working. In view of the limited number of patients likely to benefit from treatment with the artificial kidney and of the elaborate technique required it would seem to be good policy to survey the likely demand and then to establish regional units to which patients requiring treatment would be transported.

Perfusion of Organs and Tissues

We have seen that the maintenance of isolated organs, tissues or cells in a surviving condition for study has long been a standard method of investigation for physiologists. These methods, whether applied at cellular or intact organ level, require the provision of environments in which cells can carry out their usual metabolic processes. With the simplest techniques, collections of cells or thin slices of tissue can be placed in one of the many modifications of Ringer's solution and metabolic changes are inferred either from the alterations in the chemical composition of the tissue and the surrounding fluid or, more directly, from the respiratory exchanges measured in a Warburg apparatus.

But with even the thinnest slices the distance between the sustaining fluid and the cells farthest from it is much greater than the intercapillary distance *in vivo* and there is abundant evidence that the rate of oxygen uptake falls off rapidly in slices of some tissues, such as those cut from the central nervous system, when they are investigated in this fashion. And the method is obviously inapplicable when the object of study is dependent upon the integrity of the structure as in the investigation of secretory or excretory products from organs with ducts.

The technique of perfusion, that is of running nutrient fluid through an organ or tissue, either left *in situ* or isolated from the remainder of the body has yielded a rich harvest in physiological investigations. The fluid may be either blood rendered incoagulable; plasma or serum derived from blood; or a Ringer's fluid.

The perfusing fluid must be supplied at a pressure which can be derived statically from a reservoir, from a pump system, or can be provided by cross circulation from another animal. Steps in the metabolism of fatty acids in the liver, the humoral transmission of nervous impulses in sympathetic ganglia, the role of the carotid sinuses and carotid bodies in the regulation of blood circulation and breathing are mentioned as topics which, by their diversity, emphasise important advances which have been made by the employment of perfusion methods. But those using them have always been aware of the imperfections in the methods and of the limitations thereby imposed.

Before blood or plasma can be used as a perfusate it has to be rendered incoagulable. Until fairly recently, heparin and other suitable anticoagulants have not been available in large quantities and alternative methods for the prevention of clotting had to be employed. Decalcifying agents, although satisfactory in the storage of blood to be used for transfusion, were unsatisfactory in perfusion systems because, in this case, they were not diluted by a large volume of blood, as happens during transfusion. The result was that effects due to calcium lack were produced.

Usually blood was rendered incoagulable by removing fibrinogen, the plasma protein concerned in the coagulation mechanism, by stirring the blood with fine rods or wires on which the fibrinogen was deposited after conversion to fibrin. During this process blood elements were destroyed, haemoglobin was released into the plasma and the defibrinated blood acquired a property which caused constriction of small blood vessels. In ignorance of the identity of the substance, or substances, possessing this vasoconstrictor action they were labelled 'vasotonins'. In some cases, e.g. the kidney, perfusion of the organ with blood was practically impossible because the vasoconstriction was so intense that only a small fraction of what was thought to be the normal renal blood flow could be forced through the organ, even when high pressures were applied.

But Starling and Verney discovered that defibrinated blood lost its vasoconstrictor property if it was perfused through the blood vessels of lungs. With this knowledge they were able to use a living heart-lung preparation to perfuse an isolated kidney and to maintain the organ in a condition where it was responsive to hormones present in the blood. By application of this method the regulating action of the neural portion of the pituitary body was demonstrated.

Other investigators taking advantage of the ability of the lungs to remove the vasoconstrictor property from defibrinated blood found that it was possible to use mechanical pumps as artificial hearts for the perfusion of organs, including the kidney, with defibrinated blood if the blood was also perfused through the lungs to remove the vasoconstrictor properties in addition to effecting exchange of oxygen and carbon dioxide. It now seems likely that vasoconstriction was caused by the accumulation in the blood of 5-hydroxy-tryptamine which was released from blood platelets destroyed during the process of defibrination and by the mechanical disturbance of the blood in the perfusion system. Lungs remove a large proportion of any 5-hydroxy-tryptamine in the blood perfusing them.

Extracorporeal Circulation in Cardiac Surgery

In the meantime the development of cardiac surgery had raised the possibility of more ambitious and extensive operations on the heart for the correction of congenital abnormalities or for the repair of valves damaged by inflammatory processes. But it was obvious that many operations of this sort could be undertaken only if the circulation through the heart and lungs could be stopped for a period during which the heart and the great blood vessels could be opened and the interior exposed under relatively bloodless conditions. Nevertheless the circulation through other parts of the body, notably the brain and spinal cord, has to be maintained if the body is to survive. Irreparable damage is likely to be caused to the brain if its blood supply is cut off for longer than two minutes. It may also be necessary to maintain the blood supply to the heart muscle itself, through the coronary circulation, during the operation.

There are, of course, two possible solutions to this problem. One is to reduce the rate of metabolic processes by lowering the temperature of the body so that the period of circulatory standstill can be increased without danger to survival. The other possibility which I want to consider in more detail, is to maintain the body at normal temperature and to perfuse it by the establishment, through artificial means, of a circulation of blood. Provision must be made for respiratory exchanges. In this way the heart and lungs can be bypassed by an extracorporeal circulation.

The first published work on heart-lung bypass machines came in 1937 from J. H. Gibbon but it is only in the last decade that methods have progressed to the stage where these machines have been brought into regular clinical practice.

The specification of the mechanical heart-lung machine and the plan of its

operation are relatively simple. Flexible tubes are placed in the great veins close to the heart and at a selected moment, by clamping of the vessels, the whole of the blood returning to the heart, with the exception of the coronary flow, is directed to the exterior. The blood flows preferably by gravity, but in some systems assisted by suction, into an apparatus designed to effect exchange of the respiratory gases with air or a gas mixture; this is usually referred to as an 'oxygenator'. Blood is taken from the reservoir of the oxygenator by a pump and driven into the arterial system at a flow rate sufficient to meet the metabolic activities of all parts of the body and which sets up a pressure within the usual range of arterial blood pressure. The heart is now virtually empty of blood and it can be opened for the correction of congenital abnormalities or for the repair of valves. When these have been done the heart is closed and the ligatures around the blood vessels are slackened and a gradual return is made from the extracorporeal to the natural circulation.

As it passes through the oxygenator the blood should combine with oxygen to at least 90 per cent, preferably to 95 per cent, of its total oxygen capacity (90–95 per cent saturation) and the escape of carbon dioxide should be regulated so that its tension in the arterial blood will maintain the acid-base balance of the blood within the normal range. Usually, the venous blood returning to the heart, which is a mixture of blood from the veins of all parts of the body, has one-quarter to one-third less oxygen than the corresponding arterial blood. The rate of blood flow from the pump should be high enough to ensure that reduction below this does not occur otherwise it is likely that the oxygen tension in some parts may be insufficient to meet the local metabolic rates. Although there is a lack of information about the rate of energy metabolism of anaesthetised individuals which is surprising, it is likely that it is not very different from the basal metabolic rate and, therefore, making this assumption, approximate values for rates of blood flow, oxygen uptake and carbon dioxide evolution can readily be calculated. Surgical teams engaged on the development of heart-lung machines appear to have neglected this approach and worked on one or other of two different ones. Andreasson and Watson showed that survival in animals was possible after occlusion of both venae cavae and when the only channel for venous return to the heart was through the relatively small vena azygos. The size of this vessel limited the output of the heart to a small fraction of its normal value. Because there are technical difficulties in designing pumps and oxygenators which will give rates of blood flow approaching normal resting heart output there was at one period acceptance of the 'azygos flow' as a parameter for pump design. Experience has shown, however, that 'azygos flow' is too small to guarantee the survival of human patients and that in animals, it may cause the pO_2 in the brain to fall 80 per cent of the original value.

In other laboratories, the aim was to find a rate of flow from the pump at which the volume of blood in the perfused body remained at the pre-perfusion value. Above or below this rate there is transfer of blood from the pump system to the body and vice versa. Kirklin and his associates found the rate in these circumstances to be about 2·2–2·5 l./min./m² body surface and this is in close agreement with the flow rate suggested from calculation.

Design of Pumps

The first consideration in the design of a pump is that it shall cause minimal damage to the cellular elements of the blood. Other desirable qualities are: (2) its output shall be adjustable within the range of normal resting heart outputs from infants to adults, i.e. from 1 to 5 l./min.; (3) it must contain a minimal quantity of blood; (4) it must not produce foaming of the blood or gas bubbles in it; (5) it must be easily cleaned and sterilised; (6) the construction should be simple but reliable; automatic control is desirable.

Piston and centrifugal pumps have both proved unsatisfactory because of the rubbing surfaces inherent in the mode of working. These cause destruction of blood cells. Some of these pumps also cause sudden changes in velocity in the blood stream because of abrupt differences in the cross-section of the connecting tubes, the pump chamber and the valves in the piston pump. The majority of pumps which are acceptable employ an elastic tube which is alternately compressed by a rhythmically operating external force and relaxes under its own tension when the compressing force is withdrawn. Forward flow is obtained in one type of pump either by having flap or ball valves placed at each end of the tube (these have the disadvantage that flow disturbances are created as blood passes through the valve) or, as in the Melrose pump, by having the ends of the tube closed by mechanical or electrically operated clamps whose action is synchronised with the compression of the body of the tube. Minimal pressure can be exerted and except when the clamps are actually moving the contour of the tube is unaltered. Output is varied by altering the stroke of the compressor.

There are other types of pumps in which the principle of compressing an elastic tube is employed. In the Sigmamotor pump the tube is 'milked' by a series of finger-like levers, operated by cams, which compress the tube segmentally along its length against a spring-loaded back plate. The de Bakey or Jouvelet pump has the tube placed inside the circumference of a circular chamber; a rotating arm bearing a roller sweeps round the chamber compressing the tube.

Valveless pumps with a design vased on the Archimedean screw are used industrially but although they have the advantage of constant velocity of flow, little use has been made of them biologically.

The diaphragm type of pump with reciprocating movement, well known in the Dale-Schuster form, and much used in physiological laboratories has not been very suitable for application to surgery because although it has excellent mechanical properties, it is not easy to sterilise and assemble. On the other hand, tubes are easily sterilised and are dispensable.

Oxygenators

The lungs in the trained human athlete of outstanding ability are able to transfer a little more than 5·5 litres of oxygen from atmospheric air to approximately 40 litres of blood per minute. Each red blood corpuscle passes through a capillary blood vessel in the lungs in a fraction of a second. The biological engineer has found it difficult to introduce 200 ml. of oxygen from a high percentage oxygen mixture into 4 litres of blood per minute even with an exposure time of several seconds duration!

In the lungs, red blood corpuscles pass through capillaries of about their own diameter in size and are separated from the air by a membrane 1–4μ thick. There is only a plasma film between the corpuscle and the vascular endothelium. The total surface of the respiratory membrane, across which diffusion of gases occurs, is 50–70 m^2 in the adult. The total quantity of blood in the pulmonary capillaries at any instant, spread over this area, is probably 60–100 ml. No mechanical device has succeeded in imitating these conditions without injuring the blood.

The desirable qualities in an oxygenator are; (1) it must oxygenate adequately, i.e. produce 90–95 per cent saturation; (2) it should be able to introduce up to 200 ml. of oxygen into the blood per minute at the maximum flow rate of the pump; (3) it must contain a minimal quantity of blood; (4) it must produce little haemolysis; (5) it must not produce foam or bubbles; (6) it must be easily cleaned and sterilised.

Two main methods of obtaining gas exchange have emerged: one, in which the blood is spread in a turbulent film on a surface over which oxygen, or a mixture of oxygen and carbon dioxide, is flowing; the other, in which oxygen or a mixture,

is dispersed through the blood in fine bubbles with which gas exchange occurs. In the first method, in which the blood is dispersed in oxygen as in the lung, the blood film may be formed on a vertical wire mesh screen, as in Gibbon's apparatus, and the blood runs from top to bottom and is collected in a reservoir. A number of screens can be placed parallel to one another. In other applications of this method the screen is shaped into a disc or a cylinder; the disc is rotated in a vertical plane, the cylinder is rotated with its axis horizontal. The movement assists in spreading the film on the surface and keeping it in motion. The blood can be fed directly on to the disc from which it runs into a reservoir, or the moving surface may dip beneath the surface of the blood in the reservoir. In each case multiple plates are used. In Hooker's oxygenator, which was the forerunner of these types, blood was fed on to a revolving horizontal disc from the edge of which it was flung on to the interior of a stationary cylinder. The blood was damaged by this procedure and modern types are more sophisticated in their design.

The basis of the design of the oxygenators used by Jongbloed and by Melrose is somewhat similar but the blood is fed on to the surface of a revolving spiral plane.

All these oxygenators are deficient by comparison with the lungs. The maximum area on which blood can be presented is about 2 m^2 and at rotation speeds which do not produce dangerous haemolysis about 200 m^2 can be exposed in a minute. By contrast, the lung can provide about 3,600 m^2/min.

The other method of oxygenation has not, as far as I am aware, any biological counterpart. Bubbles of oxygen, or an oxygen-carbon dioxide mixture, are formed at the foot of a vertically moving column of venous blood in DeWall's method and gas exchange occurs as they pass upwards. The rate of gas flow and the size of the bubbles must be controlled to prevent damage to the blood. At the top of the column are arrangements, usually incorporating films of silicone compounds, for freeing the blood from gas bubbles before it is pumped into the arterial system. The apparatus is simple and despite the apparent difficulties of breaking down bubbles and foam the method appears to be effective judging by the clinical successes which have been obtained in the United States. It is impossible to calculate the operative diffusing area in this type of oxygenator, but on the whole, full oxygenation seems to be achieved more frequently with bubble type oxygenators than with the various modifications of the screen type, but at the expense of a greater amount of haemolysis and the risk of air emboli.

Apart from mechanical blockage of blood vessels by fibrin, anti-foaming agents or gas emboli the perfused tissues face the hazard of exposure to unusual oxygen tensions and to disturbances of the acid-base balance. To ensure maximum saturation of the haemoglobin, oxygenators are usually run on high percentage oxygen mixtures and if the oxygenator is effective this may lead, in some cases, to blood entering the arterial system with a higher oxygen tension than is usual. Opinions about the potential danger of this are varied but direct studies of oxygen tension in the brain, kidney, liver and skeletal muscle have shown that with high rates of blood flow oxygen tension may rise, particularly in the brain, above usual values. These tensions may affect the cerebral blood vessels, causing constriction; and if, in addition, the carbon dioxide tension of the blood has been reduced the cerebral vessels may constrict and the paradox may arise of cerebral anaemia despite a high oxygen tension in the arterial blood.

Control of the carbon dioxide tension at optimal level probably requires more experimental work directed to it than hitherto. Stimulation of the respiratory and vasomotor centres in the brain stem is largely dependent on carbon dioxide tension in the blood, but the tension is also involved in the regulation of the acid-base balance of the blood and the body tissues, and in the production of a particular degree of acidity. Careful monitoring shows that in many perfusions a

metabolic acidosis develops because the oxygen flow, i.e. the product of blood flow and the amount of oxygen in the blood, is too low.

Despite technical difficulties and the demonstrable biological imperfections of the methods reports are now coming from many centres throughout the world of long runs of successes in the treatment of congenital malformations of the heart and, in some cases, of valvular lesions through the use of the extracorporeal circulation.

It is clear, I think, that the outlook on and the techniques available for whole body perfusion have advanced rapidly during the last decade. But the artificial organ is not a new concept; the two which have been described have a longish history. What is new is rapid development and application of them to medical use and progress in methods has been possible because of the advent of new constructional materials with appropriate physical properties, of anticoagulants, of 'anti-foaming' substances, and of antibiotics for post-operative treatment. Much has been learned too about the necessity of combining many human skills and fields of knowledge in the building and operating of these machines for a team composed of surgeons, pump operator, anaesthetist, cardiologist, biochemist and haematologist to report on changes in blood chemistry and cytology, nurses and technicians is required. Indeed it is obvious that the complications and cost of this type of clinical work is such that it may be desirable and necessary to review the number of patients who are likely to benefit from treatment by these methods now and in the future. Is it possible, for instance, that rheumatic disease of the heart is less likely in the future ? It may be that only a few centres, kept in constant use, may meet all the demands.

There are other clinical possibilities. As with the artificial kidney, the extracorporeal circulation may be used to support an individual temporarily while the heart and circulation are flagging and in need of a period for recuperation. But if this is a likely development then it must be envisaged that while the circulatory take-over need not be complete it will be in operation for a longer period than is required for a heart operation. Problems of blood damage, disturbance of plasma proteins, maintenance of acid-base balance will become even more pressing than they are at present. There is also the possibility, as yet largely unexplored, of using perfusion techniques to subject a particular region of the body, for instance, a tumour-bearing region, to specific therapeutic agents.

Finally, these advances in the technique of perfusion may enable physiologists to make longer term experiments on isolated organs particularly in the investigation of their growth and biochemical mechanisms.

Design and Materials: Biological Engineering

The development of artificial organ systems is creating a demand for biological engineering. Design need not be based wholly on biological principles because biological systems have ways of presenting and exposing surfaces or for distributing substances which are not readily transferable to machine design and manufacture. Mechanical design should aim at the effect to be produced rather than necessarily imitate biological means and in some cases this can be achieved more simply by mechanical than by biological systems although not as compactly or with such effective automatic control.

PERCEPTION, ATTENTION AND CONSCIOUSNESS[1]

ADDRESS BY PROFESSOR MAGDALEN D. VERNON
PRESIDENT OF SECTION J

I

We tend to think that our ability to perceive what lies in front of us is so great that we can see the whole of it at a glance. Nevertheless, it often happens that we fail to perceive events taking place within the field of view; and if they are subsequently brought to our notice, we then say that we overlooked them because we were not attending. In fact, at any one moment we may perceive and be fully aware of only a small selection of the objects and events in the world around us. Some we may overlook altogether; others we may be aware of very dimly. At some times we attend only to a very small section of the field of view, as when looking down a microscope, and notice little outside that area. At other times, we perceive a wider field; we look to and fro, noticing first one thing and then another. Sometimes this is done rather inattentively; but on other occasions we may search the field of view eagerly and expectantly for a particular object or event.

It appears that there are many degrees or levels in the clarity and detail with which we are aware of our surroundings, varying from a precise and accurate perception of that part of the environment upon which attention is concentrated and focused, to a very vague marginal awareness of its less important aspects, and even to a type of perception of which we are not directly aware, but which nevertheless affects our actions in some way. In some degree we can vary the direction and extent of our conscious awareness, making it more concentrated or more diffuse, or directing it to one part of the environment rather than to others. But the degree to which we can exercise this control is limited. It is greatly affected by the general state of alertness, or 'vigilance' as it is sometimes called; by factors of motivation and interest; by learning and experience; and by features in the environment itself. But the totality of experiences of which we can be aware at any one moment seems to be limited. Thus if attention is closely concentrated on one task, irrelevant events are likely to be ignored. Again, if the eyes are fixated upon a single point in the field of vision in order that this area may be perceived accurately and in detail, then comparatively little of the surrounding area is perceived. It seems probable that we cannot attend to two events happening at one and the same moment, and perceive both of them clearly. Thus it was found that it was impossible to take in two pieces of information presented simultaneously, one visually and the other aurally (Mowbray, 1954). Unless the two different events can be combined in some way, one must be overlooked. But attention can alternate rapidly between two or more events. The time taken to switch attention from one thing to another is of the order of 1/5th of a second. Again, a figure can take on two different aspects, as in alternating perspective figures, but perception of one aspect precludes perception of the other.

If we wish to obtain a general and not very detailed view of our surroundings, we can relax our concentration and look to and fro from one point to another. Then no one part of the surroundings is very clearly perceived, and some may be overlooked altogether. Commonly, of course, we avail ourselves of a succession

[1] Address delivered to Section J (Psychology) on September 4, 1959, at the York Meeting of the British Association.

of such instantaneous impressions. If the field of view is a wide one, we look from one point to another, searching for what we want to see. Or with a narrower field, we can pick out more detail, or correct our first erroneous impressions by a further study. However, there are occasions, as in a motor accident, when we have no opportunity to look again, and we may not have time to see even the important features of the situation, if these exceed our capacity to perceive them instantaneously.

Numerous experiments have been carried out to determine how much we can see at a single glance. If a number of black dots on a white background is exposed momentarily, an observer can estimate up to five or six accurately. With a larger number, he begins to guess and is often incorrect. He is particularly likely to overlook those which are furthest from the centre of the field of vision (Baker, 1958). But if the dots are arranged in groups, or combined together in some sort of pattern, he may perceive a much larger number. If he is shown, instead of simple dots, more complex forms which he is required to describe or identify, then the number which he can perceive is reduced. But again, if the complex forms can be related together in some way, or 'coded'—if they can be combined together like the parts of a pattern or like letters in a word—they may together produce corroborative or 'redundant' information, and they will be perceived more readily.

Recently a good deal of experimental investigation has been carried out (see, for instance, Anderson and Leonard, 1958) on the effects of 'redundancy' on perception, particularly of shapes or patterns which have no ulterior meaning like that of letters, digits, diagrams or pictures. The observer has to perceive what their actual shape is, and perhaps discriminate it from other shapes. Suppose that the shapes are symmetrical, or that the patterns consist of regularly repeated items. Then the same information about form is given twice over by a shape symmetrical in one direction, and four times over by a shape symmetrical in two dimensions. The knowledge as to its essential form can be gained more rapidly than from an asymetrical shape, and for that reason it can be perceived more quickly. On the other hand, if the observer has to discriminate between similar shapes, his task may be harder when there is considerable redundancy, or repetition of pattern, because there are fewer differences between the shapes for him to discriminate. These facts are sometimes important in practical tasks involving discrimination of patterns, for instance, in radar displays. In ordinary perception of meaningful objects, however, there is much redundancy of information, that is to say, a large number of corroborative impressions which enable us to identify these objects very rapidly; and to continue to do so in conditions, for instance, of brief exposure or dim illumination, when some of the impressions are scarcely perceptible.

However, whatever the nature of the shapes or objects we wish to perceive, the total amount perceived at any one moment and the information derived from it are strictly limited. Broadbent (1958) has recently put forward the hypothesis that there is some type of 'filter' operating in the central nervous system which allows certain information to penetrate to consciousness, while preventing the access of other kinds of information. That part of the information which cannot be attended to immediately may however be put into temporary storage. When we have disposed of what immediately concerns us, we may then either turn deliberately to consider the stored information; or it may enter consciousness spontaneously; or it may affect our subsequent actions without becoming fully conscious at any time. This storage is only a short-term affair, and the information stored may soon disappear if it is debarred from consciousness for any length of time. There are, however, certain situations in which we are unable to maintain concentration indefinitely upon the matters which most concern us; and others which we temporarily keep in the background at length insist on intruding and distracting our awareness from the task in hand. We shall return to these later.

II

Let us consider first the nature of the selective processes which determine what will be most readily and accurately perceived and will tend to be focal in consciousness. And here we encounter what at first sight appears to be a paradox—that sometimes we perceive most readily familiar events to which we are well accustomed, while on other occasions it is the unusual and unexpected which erupts in consciousness. Much experimental work has demonstrated that in our normal everyday life, in circumstances which we encounter frequently, we come to expect the appearance of certain familiar objects and events; and we perceive what has the greatest probability of occurring in these circumstances. Now I think that this statement can be held to be valid in the following sense: at any one moment, the visual impressions on the retina and in the central nervous system are often too limited, vague and ambiguous to define exactly the objects to which they refer. Nevertheless, they provide cues which in so far as they corroborate one another may lead to inferences as to the nature of what is present—inferences based on expectations derived from past experiences which have taught us what it is most probable that we should perceive. Thus in fact we may believe ourselves to be aware of something on the basis of very inadequate sensory data—and perhaps of something which is not there at all. In an often quoted demonstration by Ames (1946), a trapezoidally-shaped window revolving about a vertical axis was perceived, especially in monocular vision, as a rectangular window oscillating to and fro. In another demonstration Ames showed what was called the distorted room, in which walls, floor and ceiling were slanted at various angles, instead of being at right angles to one another. But if viewed with one eye through a small hole in a screen, the sensory impressions were similar to those produced by a normal rectilinear room, and that in fact was what the observer perceived. There seems thus to be a tendency to 'make sense' of what is perceived only partially, vaguely or momentarily; and 'making sense' means that we perceive what may reasonably be inferred from our general knowledge of the situation to be the source of our sensory impressions. Indeed, it may be that we hardly perceive at all in the ordinary sense of the word; but we infer from the vague sensory impressions that what is there is a rectangular window or a rectilinear room, because there is a greater probability that we are being confronted with these objects than with a trapezoidal window or a distorted room.

But there are several ways in which the expectations of an observer may be altered, so that he no longer perceives what is most probable or most likely to be before him. His expectations may be modified if he is told to look out for certain things, or certain aspects of the situation. Numerous experiments have shown that an observer may be 'set' to perceive by the instructions given him by the experimenter. When observers were told that they were going to be shown in a brief exposure words relating to 'animals', and were then shown groups of letters such as 'seal' and 'wharl', they often reported words such as 'seal' and 'whale' (Siipola, 1935). But when they were told that the words would be related to 'boats', they reported 'sail' and 'wharf'.

If observers are instructed beforehand to attend particularly to one aspect of a complex field—a field, for instance, which contains numerous types of shape of different colours—they will report this aspect with greater accuracy than if they had not been so instructed. But they will be more likely to overlook the other aspects, and be able to report very little about them. If observers are asked to discriminate shapes, certain characteristics of which are irrelevant to their judgments, these judgments will also be slower and less accurate if the observers think that these characteristics may sometimes be relevant to their judgments; but there is no such effect if the observers are instructed beforehand that these characteristics can be disregarded as altogether irrelevant (Henneman, 1957). However, another

experiment (Lawrence and Laberge, 1956) showed that in fact observers may perceive something of the characteristics of figures to which they have not been directed to attend. For a short period of time after the figures have been presented, the observers may be able to store in their memories these secondary aspects, but they soon forget them. In several experiments it has been found that similar results are obtained if the observer is told to respond to a particular shape shown with a number of other shapes, and is informed beforehand as to how many different shapes there will be. The smaller the number of possible alternatives from which he has to choose, the quicker and more accurate will be his perceptions. Thus these experiments all show that a 'set' can be established to attend to some particular aspect of the field which 'filters' perception and concentrates it upon one aspect rather than others; but nevertheless the latter need not be completely overlooked.

There is a number of situations in which expectation of what is most probable has been modified by learning, and the observer has been 'set' by training to perceive aspects of the environment which he would otherwise have overlooked. We have all heard stories of native trackers who can perceive the spoors of wild animals in the jungle which are invisible to Europeans. In our own society, tea-tasters and wine-tasters learn to perceive qualities in tea and wine which are not apparent to the ordinary person. In many industrial occupations, people learn to grade materials from small not easily perceptible characteristics. Now, there are two types of process which may take place in perceptual learning: (1) improvement in the perceptual discrimination of particular forms or objects, or the differences between these; (2) a more general type of judgment based upon inferences made from what is perceived. Practice in the recognition and discrimination of particular forms can undoubtedly improve these processes. The observer may get to know the shapes of particular forms (see, for instance, Bevan and Zener, 1952); or his actual acuity may appear to improve because he learns to find and utilise finer and more accurate cues to discrimination (Bruce and Low, 1951). But it may be necessary with complex material to point out to the observer just what he is to notice. For instance, in learning to identify aircraft, observers will improve most quickly if they are shown just what are the significant points of difference between different aircraft. But this type of training is usually specific to a particular situation or class of material; it does not produce any general improvement in perception. It has sometimes been claimed that practice in the discrimination of shapes will improve the ability to read letters; but there is no reliable evidence for this. Again, practice in the rapid perception of letters and words exposed momentarily may improve this ability, but have little effect on ordinary reading.

However, people may also be trained to utilise their percepts efficiently in making judgments or inferences from them. Thus it has been shown that absolute judgments of distance could be improved when the observers were taught how to break up long distances into smaller units which they then judged directly in yards (Gibson *et al.*, 1955). Such judgments can usually be improved by teaching observers to note certain cues in the situation against which they can match their percepts; and the method of judgment can often be generalized to a variety of similar situations. In all these forms of learning, the essential feature is that something is perceived which was not noticed before; and in so far as the observer practises concentrating his attention upon that characteristic, so in time he will come to notice it automatically without further difficulty.

III

There are circumstances, however, in which people spontaneously perceive certain things or certain aspects of the field of view particularly readily. If they have strong

feelings about what is shown them or if they desire to perceive or to avoid perceiving something, then not only is the speed of perceiving altered; they may even think they perceive what is not actually there—or if they don't want to see it, they may even think they perceive what is not actually there—or if they don't want to see it, they may fail to do so when it is, as we say, staring them in the face. Experiments have been carried out (Sanford, 1936, and Levine, Chein and Murphy, 1942) in which hungry observers were shown pictures of food, or objects related to food, for brief periods of time, or partially obscured. They perceived the food objects more quickly than observers who were not hungry; and also thought they saw food when no pictures of food were shown them. However, in some cases, as they became hungrier and hungrier, they identified fewer of the pictures, presumably because their need for food was not in fact satisfied by merely perceiving pictures of it. But the fact that we perceive more quickly something we are motivated to see does not mean that we necessarily perceive more correctly. In everyday life, if we find that in such circumstances we are mistaken, we may be able to rectify our mistakes by looking again. But one experiment showed that observers who were rewarded for guessing the identity of a single shape picked out from a large scattered group of shapes did not become more accurate at this task; they merely made more incorrect guesses (Boynton, 1957).

The influence of emotions and desires on perceiving also appears in our everyday life perceptions of other people. We perceive most clearly and remember in most detail the faces of those in whom we are interested, and notice less clearly the faces of those to whom we are indifferent. A group of white American students who were favourably disposed towards Negroes perceived and recognised photographs of Negroes more correctly than did students who were unfavourable in their attitudes (Seeleman, 1940). The former perceived the faces in the photographs as those of particular individuals, with clearly differentiated individualities. The latter lumped them together as 'niggers', and therefore saw little recognisable difference between them. But in another experiment (Secord *et al.*, 1956) it was shown that a group of people prejudiced against Negroes accentuated the differences between Negroes and whites in characteristics such as width of nose, fullness of lips, etc., to a greater extent than did a group of non-prejudiced people.

Thus what we perceive and pay attention to may also be modified by unpleasant feelings. The general rapidity and accuracy of perceiving may be decreased if it follows immediately on a disagreeable experience, and in particular one in which people have been made to feel frustrated, thwarted or inferior. Thus observers who were given a task which they could not perform successfully were slower and more inaccurate in their subsequent perceptions, particularly if they had been reproached or ridiculed for their failure (Verville, 1946). Again observers who after an experience of failure were then shown a series of blurred and ambiguous figures began guessing what these were *sooner* than did observers who had experienced success; but they also took *longer* to identify the figures correctly (Smock, 1955). In other words, they were both hasty and inaccurate.

Sometimes, however, perception appears to be retarded by unpleasantness or anxiety associated with the material which is being perceived, rather than with some previous experience. Several experiments have been devoted to what has been termed 'perceptual defence'. Observers were shown in brief exposure sexual words which are taboo in polite conversation; and it appeared that many of the observers were slower to perceive these than to perceive neutral words which have no such connotation (see Bruner and Postman, 1947). It was hypothesised that these taboo words were perceived without their reaching consciousness, and were then refused entry to full consciousness because they would provoke disgust or anxiety. But it may be that the observers were unfamiliar with some of the words; or else they guessed what they might be, but rejected their guesses on the score that it was

unlikely that such words would have been shown them; or else they knew what they were, but were shy of uttering them. When these various possibilities were eliminated, it was often found that the taboo words were perceived as quickly as the neutral ones. Indeed, in some cases observers exhibited 'perceptual sensitisation', and perceived the taboo words more readily than the neutral ones.

There are other situations in which 'perceptual sensitisation' seems to occur; when highly significant events appear to have a 'prior entry' and to force themselves into consciousness without there being any preliminary expectancy or state of desire in the observer. We all know the rapidity with which we perceive a sudden bright light or a loud noise, a blow or other painful stimulus; and how we immediately take action, by starting, jumping aside, shielding our eyes or ears. Now it might be argued that it is the great intensity of these stimuli which ensures that they shall blot out everything else and rapidly enter consciousness. Intensity may indeed be one of the factors concerned, but there is evidence to show that it is not the only one, and that these stimuli are significant also because they constitute a potential threat to us, and it is important that we take immediate action to avoid them. Thus intense stimuli, if repeated or prolonged, may cease to be central in consciousness. It is possible to ignore the loud noise of traffic in the street outside, and even sleep in spite of it, but to awake immediately at the sound of someone opening the bedroom door. Therefore it appears that suddenness and unexpectedness may be the important factors in bringing these events to consciousness. Again, we may quickly become aware of a sudden change in the perceptual field, and especially of rapid movement, without at first perceiving *what* is changing or moving. But once it is realised that there is something unexpected or incongruous in the field of view, then the tendency is to devote more attention to that part of the field than to its more familiar and humdrum aspects (see Berlyne, 1957, 1958)

IV

From these observations we may then predict what are the situations and events of which we are least likely to become aware, and which we find most hard to attend to over any length of time. These are, first, stimuli which are very brief, very dim (because they are blurred or dimly illuminated) or situated at the margin of the field of vision. Secondly, they are situations which remain comparatively unchanged over long periods of time. We all know that if the intensity of a light or a sound is reduced sufficiently we cease to be able to perceive them. If we have cause to make a considerable effort, we may continue for a time to perceive them; but no effort nor desire, however strong, will make them perceptible below a certain minimum intensity—which is termed the 'threshold intensity'. Much experiment has been devoted to measuring the physical values of the threshold intensities for light and sound. It has been shown that these values are comparatively constant, in favourable conditions, but not completely so. It seems that awareness of such stimuli fluctuates; at one moment they can be perceived, but not at the next. The cause of this fluctuation lies probably in the nature of the physiological mechanisms of sensation. However, it is also true that different observers vary in the consistency with which they report that a stimulus of low intensity has appeared or disappeared; experience in making these judgments usually produces an increase in consistency.

Nevertheless, evidence has been obtained in recent years to show that events of which observers are not consciously aware may yet influence their thoughts and actions. An instance of this may be the phenomenon of 'perceptual defence' which we have already considered. One experiment (McGinnies, 1949) appeared to show that before the observer became sufficiently aware of taboo words to be able to report them, he yet gave a psychogalvanic reflex response to them. (This is a

reflex decrease in the resistence of the skin to an electric current, which occurs as part of the response of the autonomic nervous system to painful and emotional stimuli). In another experiment, nonsense syllables, some of which had previously been associated with electric shocks, were presented for perception during brief intervals of time (Lazarus and McCleary, 1951). Psychogalvanic reflex responses occurred when the previously shocked nonsense syllables were shown, before the observer perceived what the nonsense syllables were. It was claimed that a process called 'subception' was taking place, setting up responses of the autonomic nervous system to stimuli with painful associations, even when these were not consciously perceived. However, it is possible that the observers did in fact see parts of the nonsense syllables, though not enough to report them correctly. But evidence of a similar kind has been obtained by Dixon (1955), that is to say, of psychogalvanic reflex responses to sexual words which were presented below threshold intensity, and were therefore never consciously perceived.

Now it has been shown that even in sleep psychogalvanic responses may appear not only with loud noises, but also with faint but significant sounds such as the whispering of the observer's name (Jung, 1954). This may happen without the observer waking; or if he does wake, he does not remember what stimulated him. The psychogalvanic response is nevertheless accompanied by changes in the natural brain rhythms of sleep, as shown in the electro-encephalogram, changes such as characterise the transition from sleep to wakefulness. Thus clearly there is a mechanism in the brain which can respond to certain types of stimulation, of potential importance to the individual, and although he does not become aware of their precise nature, yet his autonomic nervous system may react to them as to an alarm or emotional threat.

But Dixon (1955) also obtained evidence as to other effects produced by 'subliminal stimulation', that is to say, by stimuli below threshold intensity, but only just below. His observers were asked to say the first words that came into their minds when each of the stimulus words was presented subliminally; and often they responded with words which had some meaningful association with the stimulus words. With the sexual words, this sometimes had a Freudian character. Again, the observers were frequently able to associate their responses to the corresponding stimulus words when these were shown them subsequently. In other experiments Dixon found that such associations occurred only when they had been long established by use and familiarity. All these effects were more likely to occur if the observer had been instructed beforehand to expect that he was being stimulated in this way. Even when there was no such instruction, the observers were concentrating upon the task of guessing, so that there was little competition from other forms of conscious perception.

There are other situations in which the observer has apparently not been fully conscious of an event at the time of its original occurrence; but he has in fact perceived and remembered it, and it has reappeared more or less consciously somewhat later. Thus in the phenomenon called 'incidental memory', an observer perceives events, is not directly conscious at the time that he has done so, but nevertheless acts in such a way later as to show that he had in fact registered them. In an experiment by Belbin (1956), road safety propaganda posters were hung on the walls of a waiting room in which observers sat for three minutes before they went into another room to be tested. Although they all seemed to have realised that there were posters in the waiting room, they neither perceived nor recalled them as such with any accuracy. But they were then tested to discover if they could apply the warnings given in these posters by picking out from photographs of traffic scenes any faults they could see in relation to road safety—such as pedestrians failing to give way to traffic which had been signalled on by a policeman. Now it was found that car-drivers picked out from the photographs significantly more faults suggested

by the posters than did non-drivers. This was not due simply to their driving experience, since a control group who had not seen the posters did not show the effect. But apparently the drivers, set by their driving experience to assimilate warnings of this kind, did in fact register them and act on them though they were not fully conscious of having perceived them.

V

We have already noted that material projected for a very brief period of time will not be perceived. If it is shown for about 1/100th of a second, the observer may be aware that there is something there without being able to say what it is. Perception will increase in accuracy and detail with increase of exposure time; at intermediate stages, it is determined to a considerable extent by what the observer expects to see. It has been shown also that a figure exposed for too short a time to be perceived itself may nevertheless affect what is perceived immediately afterwards. In one experiment (Smith and Henricksson, 1955), a smiling face was presented for a period of about 1/10th of a second, followed immediately by an unsmiling face. The observer was not aware of the first face, but the second one appeared to be smiling slightly, and the smile increased as the exposure time of the first face was increased. Again, a square preceded by a set of radiating lines appeared distorted in shape, as if the lines had been simultaneously superimposed upon it. In other experiments, the second figure became blurred or darkened, or changed in size, by presenting another figure immediately before it. These and other experiments indicate the combination of two events when there is insufficient time for both to be perceived independently. It seems that all percepts take an appreciable period of time to develop in the central nervous system. Thus if a second stimulus arrives before the first one has had time to develop, the first will not be fully perceived, but some partial perception of it may combine with and affect the perception of the second.

VI

We must now consider the situations in which perception is at first reasonably clear and accurate, but later ceases to be so. This seems to occur particularly when the observer is required to perceive a long series of very similar events, and when there is comparatively little change in the external situation over a long period of time. Such a situation was that in the 'clock test' designed by Mackworth (1950). A pointer rotated in successive small jumps, one every second, round a dial like that of a clock; and at irregular and comparatively infrequent intervals it made a double jump. Observers had to notice and signal each of these double jumps by depressing a key. After only about half-an-hour, they began to miss the double jumps; and the number missed increased, throughout a two-hour period. Efficiency could be maintained, however, by increasing motivation; and by signalling to the observer every time a double jump had occurred, telling him whether or not he had responded to it.

However, the perceptual characteristics of such tasks are also important in maintaining efficiency of response. In an experiment in which observers had to report the occurrence of the 'echo' on a mock-up radar screen, there was a sharp decline in efficiency when the echo was dim and difficult to see, but relatively little decline when it was bright and clear (see Broadbent, 1958). Lengthening the time over which a signal is visible and increasing its frequency and regularity of appearance may also prevent decline, because the observer can expect when it will occur. But a simultaneous loud continuous noise enhances the decline. These experiments thus demonstrate that a decrease in 'vigilance' and awareness of repeated signals may occur in a monotonous serial task, but this decrease may be

prevented by certain methods of emphasising the signals or making them clearer. Broadbent (1958) has explained these effects as being due to an inability to maintain any concentration of awareness on a relatively unimpressive and unchanging situation over a long period of time. Sooner or later there occur blockages in perception, and a wandering of attention to other features of the environment or to the observer's own thoughts, and an event occurring during this period goes unnoticed—though this is less likely to happen if the event is expected. The shorter the duration of the signal, the more likely is it to occur in one of these blockages, and therefore to be overlooked. But presumably the wandering is prevented by more frequent and more intense stimuli. Again, a paced task such as that of the clock test is more affected than is an unpaced task in which signals remain on view for a considerable period of time. Thus in another experiment (Broadbent, 1958), an observer had to make a response to any one of twenty dials which showed a a 'danger' reading. The 'danger' reading continued to be visible until the observer had responded to it, that is to say, until any temporary lapse of attention had disappeared. There was some oscillation of vigilance, but no overall decrease.

Again, we know from earlier experiments on the deterioration of performance of aircraft pilots during long periods of work (see Bartlett, 1943), that in these circumstances attention wanders to an increasing extent from signals on instrument dials. But it is important to note that this occurs not only as the result of general fatigue, but also from repetitiveness and lack of variation in perceptual stimulation. The application of these findings to the performance of monotonous tasks is obvious; and Colquhoun (1957) has begun a study of the factors which are most likely to produce loss of vigilance in industrial inspection tasks.

Even more startling results as to the effects of an unchanging environment have been obtained in studies made at McGill University (Bexton *et al.*, 1954; Heron *et al.*, 1956). The experimenters induced observers by paying them considerable sums of money to remain over a period of 2–5 days in an environment in which almost all sensory stimulation was kept constant. The observer lay on a bed; he wore translucent goggles over his eyes so that he could see nothing but a blur of light; he could hear only an unvarying buzz; and he was prevented from touching anything by cuffs which came down over his hands. Although at first most of the observers slept a great deal, after about 24 hours they could sleep only in snatches. They became bored and restless, and several of them were unable to endure the experiment much longer. Their tested intelligence deteriorated, they could not concentrate on anything and they suffered from visual and auditory hallucinations. When they emerged from their incarceration, their perception of the visual field was distorted, and objects appeared blurred and unstable.

These results have since been paralleled by studies made of the effects of placing people in a tank-type respirator such as those used for polio patients, in which they are kept more or less motionless, as well as receiving little or no variation in sensory stimulation of other kinds (see Leiderman *et al.*, 1958). Their experiences were similar to those of the McGill observers—anxiety, loss of concentration and hallucinatory phenomena. Only five out of seventeen could endure the respirator for more than 36 hours. Similar hallucinatory phenomena were observed in polio patients placed in these tank-type respirators; and also in patients immobilised for fractures and cardiac disorders, when their sensory environment was restricted and monotonous. Thus it appears that experiences normally unconnected with the perceptual environment may also be affected if the latter is of prolonged duration. Changing perceptions are necessary to preserve mental alertness and normal powers of thought.

Evidence from studies of animal behaviour have indicated that such experiences during infancy may have a permanent effect on adult behaviour. It was found that young rats brought up in varied environmental surroundings providing a diversity

of perceptual stimuli were in adult life more active and ready to explore their environment than those brought up in more stereotyped surroundings. They were more intelligent in their behaviour, and better able to discriminate between perceptual stimuli (see Barnett, 1958). A chimpanzee whose head was covered by a translucent screen during infancy, so that it saw only an unchanging light, was extremely deficient in the ability to discriminate and identify objects when normal vision and touch were restored (see Hebb, 1958). Indeed, it behaved as if it was totally blind.

VII

The psychological evidence as to variations in conscious awareness which occur in various types of perceptual situation and with varying degrees of attention has been related in recent years to certain physiological processes occurring in the central nervous system; and especially to the functions of a particular type of nerve tissue in the subcortical region of the brain called the 'reticular formation'. The activities of this appear to be associated with the arousal of awareness, the maintenance of vigilance and the direction of attention to specific events (see Jasper, 1957, and Samuels, 1959). The functions of the reticular formation seem to be two-fold. In the first place, one part of it appears to be concerned with general arousal and wakefulness. Impulses from this part inhibit the spontaneous activity of the cortex which occurs in the long slow synchronous rhythms appearing in the electroencephalogram during sleep; and these rhythms are replaced by the more rapid alpha rhythm which characterises waking states in which attention is relatively relaxed; and which in turn is blocked by direct sensory stimulation or when attention is aroused. The reticular formation is itself stimulated to action both by impulses arriving through collateral fibres from the sensory nerve tracts; and also by impulses coming from the cortex. The latter arise particularly in sudden and unexpected stimulation of the cortex, and their effect appears to be relatively temporary. After partial arousal to wakefulness, repetition of stimulation produces habituation, arousal is inhibited and sleep restored. Injuries to the reticular formation produce a condition of lethargy or coma in animals, which cannot then be aroused.

But another part of the reticular formation appears to be concerned with more specific alerting to particular sensory stimuli. Impulses from this part may interrupt and re-set the general pattern of cortical excitation; enhance or recruit discharges in specific areas of the cortex; and inhibit discharges in other areas. In visual stimulation, they block the alpha rhythm of the visual areas of the cortex. This part of the reticular formation is also stimulated by impulses through collaterals from the specific sensory pathways. It is affected to the greatest extent by pain impulses; and auditory impulses produce more effect than do visual ones. These differences would appear to reflect the relative degree of attention paid to these different sensory modes.

The activities of this part of the reticular formation are also very closely geared to and dependent upon impulses from the cortex. Sensory impulses passing up the direct pathways to the cortex travel at higher speeds than those proceeding through collaterals to the reticular formation. Thus there is time for the cortex to evaluate the former and to discharge downwards to the reticular formation, regulating its reactions to the sensory impulses it receives through collaterals. Its facilitatory activities may then be directed towards percepts significant to the individual, and its inhibitory activities towards irrelevant percepts, producing an enhancement of discrimination. Such an enhancement has been demonstrated in an experiment in which people were required to distinguish between two successive flashes of light (Lindsley, see Jasper, 1957). It was found that the temporal interval necessary for

discrimination between the flashes was shortened by direct stimulation of the reticular formation.

We may then infer that although the direct sensory pathways transmit the information which forms the actual content of consciousness, the degree of awareness of this and the manner in which it is discriminated depend on the activities of the reticular formation. This is demonstrated by the effects of stimulation by barbiturate drugs. The activities of the reticular formation are depressed and inhibited by concentrations of these drugs which are insufficient to affect direct responses of the sensory areas of the cortex. Thus an individual may continue to be aware of sensory stimulation after he has lost the power to attend or discriminate.

The functions of the reticular formation have also been shown to be affected by impulses from those areas of the cortex specifically involved in motivational and emotional states. General arousal, specific anticipatory 'set' and attentive searching with the eyes, followed by exploratory behaviour, are set up through the activity of the reticular formation. Similar effects have been demonstrated by direct electrical stimulation of the reticular formation in monkeys. Thus mild stimulation produced the arousal of sleeping monkeys and the attention and alerting of waking animals, with inhibition of voluntary movement. Higher intensities of stimulation produced fear reactions of cowering and avoiding; still higher intensities, panic flight. Strong electric shocks to the area of the cortex associated with motivational and emotional functions may, however, result in a complete blockage of activity in that part of the reticular formation concerned with specific alerting and attention. This effect seems to parallel the breakdown of discrimination which takes place in states of violent emotion; it may even occur in a mild form in 'perceptual defence'.

VIII

This evidence as to the functions of the reticular formation appears to show that there are two separate and distinct processes which can occur in our reactions to the environment: first, a general and non-focal perception or registration of the environmental field or some part of it, which may include little or even no conscious awareness; and secondly, a focalised attention to some particular part of the field, accompanied by maximal conscious awareness. The latter process has been likened to a 'spotlight' focused upon a small area of the field, the remainder of which is only dimly lit. The greater the degree of attention, the greater the clarity in the awareness of that part which is attended to. But although in such conditions perception is generally rapid and accurate, it can nevertheless take place also when there is little or no attention; and the precise relationship between perception and attention is difficult to define or determine.

The concept of a spotlight focused upon a particular area of the field is obviously applicable to situations such as those in which an observer is required to perceive and report the number and nature of objects exposed in a small area for a brief period of time. In such circumstances, the amount perceived is certainly limited by the maximal attentive and receptive capacity of the observer. But whether this capacity is exercised to the full is partly a function of physical conditions such as the brightness, contrast, heterogeneity and form qualities of the field; and also of factors in the observer himself related to his expectations as to what will appear and his ability to 'code' the information supplied him and to assimilate its meaning. But also it seems that no one is capable of exercising his full capacities for attention and perception over more than a limited period of time in a relatively unchanging environment, apparently through some process of habituation or self-inhibition in the functions of the reticular formation.

However, we have seen that perception is by no means limited to that part of the field upon which attention is maximally focused. Observers are certainly aware of

something in the surrounding areas of the field, though it is difficult to determine at all exactly what and how much is perceived; how much is remembered and for how long; and what effect it has on the observer's thoughts and behaviour. But we have noted that in some cases aspects of the field appear to be registered in such a way as to produce effects even when the observer is barely conscious of having perceived them, or is not conscious of them at all. Again, parts of the field may be perceived in varying amounts and with varying correctness when attention is not focused—when it is extremely diffuse, and the observer allows it to wander in an undirected fashion over the field. It seems that in these circumstances certain objects or events in the field may 'arrest' attention, which will then be focused upon them. These events may possess characteristics such as intensity, vividness or sudden appearance which cause this effect. Or they may appeal to the observer's desires or interests, or may be a potential threat of danger to him. But we also have the parodoxical situation in which certain events which might cause anxiety or unpleasantness are apparently excluded from consciousness. Possibly, in the first case the general arousal function of the reticular formation is stimulating a general alerting of consciousness to the situation as a whole; whereas in the second case specific attentive discrimination is inhibited by a downward discharge from the cortex in response to emotional shock.

However, in all these cases some process of 'filtering' appears to take place below the level of consciousness, which allows certain percepts to penetrate to full consciousness, and directs attention upon them; whereas other percepts are marginally conscious and are stored for a while until we can attend to them; yet others never become more than vaguely conscious. But the marginal percepts may in fact have considerable effect on behaviour, particularly upon the more automatic types of behaviour. The type of 'filtering' and the direction of attention vary according to the significance of the situation to the observer, and are subject to the effects of learning. It has been hypothesised that the functions of the reticular formation itself may be modified considerably by learning; but more evidence is required to determine the manner in which this takes place.

References

Ames, A. (1946): *Some Demonstrations concerned with the Origin and Nature of our Sensations. A Laboratory Manual.* Dartmouth Eye Institute.

Anderson, N. S. & Leonard, J. A. (1958): *J. Exp. Psychol.* **56,** 262.

Baker, C. H. (1958): *Brit. J. Psychol.* **49,** 279.

Barnett, S. A. (1958): *Brit. J. Psychol.* **49,** 289.

Bartlett, F. C. (1943): *Proc. roy. Soc.* B, **131,** 247.

Belbin, E. (1956): *Brit. J. Psychol.* **47,** 259.

Berlyne, D. E. (1957): *J. Exp. Psychol.* **53,** 399.

——(1958): *J. Exp. Psychol.* **55,** 289.

Bevan, W. J. & Zener, K. (1952): *Amer. J. Psychol.* **65,** 434.

Bexton, W. H., Heron, W. & Scott, T. H. (1954): *Canad. J. Psychol.* **8,** 70.

Boynton, R. M. (1957): In *Form Discrimination as Related to Military Problems.* Ed. by J. W. Wulfeck & J. H. Taylor. Washington: Nat. Acad. Sci.—Nat. Res. Counc., Publication 561.

Broadbent, D. E. (1958): *Perception and Communication.* London: Pergamon Press.

Bruce, R. H. & Low, F. N. (1951): *J. Exp. Psychol.* **41,** 275.

Bruner, J. S. & Postman, L. (1947): *J. Personality,* **16,** 69.

Colquhoun, W. P. (1957): *Nature, Lond.,* **180,** 1331.

Dixon, N. F. (1955): *The Effect of Subliminal Stimulation upon Cognitive and Other Processes.* Unpublished Ph.D. Thesis, University of Reading.

Gibson, E. J., Bergman, R. & Purdy, J. (1955): *J. Exp. Psychol.* **50,** 97.

Hebb, D. O. (1958): *A Textbook of Psychology.* London: Saunders.

Henneman, R. H. (1957): In *Form Discrimination as Related to Military Problems.* Ed. by J. W. Wulfeck & J. H. Taylor. Nat. Acad. Sci—Nat. Res. Counc., Publication 561.

Heron, W., Doane, B. K. & Scott, T. H. (1956): *Canad. J. Psychol.* **10,** 13.

Jasper, H. H. *et al.*, Editors (1957): *Reticular Formation of the Brain.* Henry Ford Hospital International Symposium. London: Churchill.

Jung, R. (1954): In *Brain Mechanisms and Consciousness.* A symposium organized by the Council for International Organizations of Medical Sciences. Oxford: Blackwell.

Lawrence, D. A. & Laberge, D. L. (1956): *J. Exp. Psychol.* **51,** 12.

Lazarus, R. S. & McCleary, R. A. (1951): *Psych. Rev.* **58,** 113.

LEIDERMAN, H., MENDELSON, J. H., WEXLER, D. & SOLOMON, P. (1958): *A.M.A. Arch. Internal Medicine*, **101,** 389.
LEVINE, R., CHEIN, I. & MURPHY, G. (1942): *J. Psychol.* **13,** 283.
MACKWORTH, N. H. (1950): *Researches on the Measurement of Human Performance*. M.R.C. Spec. Rep. Ser., No. 268.
MCGINNIES, E. (1949): *Psych. Rev.* **56,** 244.
MOWBRAY, G. H. (1954): *Quart. J. exper. Psychol.* **6,** 86.
SAMUELS, I. (1959): *Psychol. Bull.* **56,** 1.
SANFORD, R. N. (1936): *J. Psychol.* **2,** 129.
SECOND, P. F., BEVAN, W. & KATZ, B. (1956): *J. abnorm. (soc.) Psychol.* **53,** 78.
SEELEMAN, V. (1940): *Arch. Psychol.*, No. 258.
SIIPOLA, E. (1935): *Psychol. Monogr.* **46,** No. 210, 27.
SMITH, G. J. W. & HENRICKSSON, M. (1955): *Acta Psychol.* **11,** 346.
SMOCK, C. D. (1955): *J. abnorm. (soc.) Psychol.* **50,** 177.
VERVILLE, E. (1946): *J. genet. Psychol.* **69,** 133.

PLANTS ON LAND AND IN THE OCEANS[1]

ADDRESS BY DR. W. R. G. ATKINS, C.B.E., O.B.E. (Mil), F.R.S.

PRESIDENT OF SECTION K

LADIES AND GENTLEMEN,

My first duty is to thank you for your action, through your Council, in doing me the honour of appointing me as President of the Botanical Section of the Association. This came as a very great surprise and gives me the opportunity to discuss the applications of botany in the oceans and to show the sort of problems and difficulties that may confront botanists.

How do we all begin our own knowledge of nature—of plants? We look first through the eyes of a child:

> Up into the cherry-tree
> Who should climb but little me?
> I held the trunk with both my hands
> And looked abroad on foreign lands.
>
> I saw the next door garden lie,
> Adorned with flowers before my eye,
> And many pleasant places more
> That I had never seen before.
>
> If I could find a higher tree
> Farther and farther I should see
> To where the grown-up river slips
> Into the sea among the ships.

This is what we all want, a higher tree, a more powerful telescope, or microscope, a more sensitive galvanometer or valve.

Like Stevenson, I too hope to take you among the ships—and to essay the task set by another poet, Edmund Spenser:

> O what an endlesse worke have I in hand
> To count the sea's abundant progeny
> Whose fruitful seede farr passeth those in land
> And also those which wonne in th' azure sky!
> For much more eath to tell the starres ar by
> Albe they endlesse seeme in estimation,
> Then to recount the Sea's posterity
> So fertile be the flouds in generation
> So huge their numbers and so numberlesse their nation.

Spenser seems to have posed this problem of life long before any man of science had considered it! And indeed it is with a peculiar pleasure that one finds observations, ordinarily recorded in the precise words of scientific usage, appearing in the beautiful and fanciful diction of the poets. The following examples may be familiar to many, but I have not seen them mentioned elsewhere in this connection.

Incomparable odes are, to us, a gift from the genius of Keats, and the poet's keen observation leads, in 'To a Nightingale' to the lines

> But here there is no light,
> Save what from heaven is with the breezes blown
> Through verdurous glooms and winding mossy ways.

[1] Address read by Dr. C. P. Spencer to Section K (Botany) on September 3, 1959, at the York Meeting of the British Association.

These lines I had known for years without realising how foolish seemed the blowing of light. I understood it one day when measuring the daylight factor in a wood, with an instrument which gave wide variations to and fro in its readings. Keats had seen the starlight as the trees swayed!

Who could stamp the features of a winter woodland more concisely than did Coleridge with

> And naught was green upon the oak
> Save moss and rarest mistletoe.

To quote J. B. Firth, 'Poetry has been described as "the shortest way of saying a thing; That is why, by the beguiling aid of rhyme, Poetry is more easily remembered than Prose,"'—and down through the centuries rolls that masterpiece of the poetic description of nature, the *Georgics* of Virgil.

> From Mantuas meadows to imperial Rome
> Came Virgil, with the wood-light in his eye.

In our ordinary lives we are of necessity beset by the commonplace and the trivial. But we have the clarion call of our great Milton:

> The mind is its own place, and in itself
> Can make a heav'n of hell, a hell of heav'n.

We have too the quiet reasonableness of St. Paul,

> Whatsoever things are true
> Whatsoever things are honest
> Whatsoever things are just
> Whatsoever things are pure
> Whatsoever things are lovely
> Whatsoever things are of good report;
> If there be any virtue, and if there be any praise, think on these things.

Surely scientific studies and research fit well into this classification of thoughts. I commend botany not only as a profession but as a way of life.

The first meeting of Section K that I attended was in Hull, in 1922, when Professor H. H. Dixon was president. He had taught me. I had been his assistant and collaborator and he honoured me by his friendship for the rest of his life. Looking over the list of sectional presidents since 1895 it is obvious that the majority were holders of university chairs or appointments. My own career having been very different, I venture to mention some lines of work which, if not all botany, were at least I think such as to be greatly helped by some knowledge of botany. Entering Trinity College, Dublin University, in 1902 in the first year's medical course, I came under the kindly care of Edward Perceval Wright, our Professor of Botany, a great systematist and collector, also keeper of the Herbarium. Sir Almroth Wright was his nephew. That autumn Dixon became Professor and later in 1906 Director of the Botanic Garden. The new School of Botany was erected in 1907. We worked there on osmotic pressures and on the carbohydrates of sap centrifuged from lengths of wood. I also worked on oxidases and attempted to determine the first sugar of photosynthesis. Then after work on explosives in the Royal Arsenal, Woolwich, I went to the National Physical Laboratory at Teddington and gained experience in testing the durability of linen and cotton fabrics used for aeroplanes and balloons. I could visit Kew! On the recommendation of Sir Richard Glazebrook I was commissioned and sent to Egypt in July 1916. Problems were lying around. One was to find which was the best kind of wood for aeroplane propellers. Many became unserviceable before use. Methods of preventing damage from dew or rain had to be tested, as had also means of reducing sand erosion of the blade tips. Could one, to meet a shortage, use for a longitudinal spar (a longeron) wych-elm instead of ash?

The wych-elm was straight grained and a determination of 'Young's modulus' appeared satisfactory. It was used. When the machine crashed the ash longeron was fractured. Well, I expect it had had a greater strain!

The propellers were made of about seven laminations, glued together. To minimise shrinking, which resulted in ridges and great loss of efficiency, someone in England got them sent out in tin-lined cases, hermetically sealed. For careful packing the cases were filled with 'green' sawdust! The glue was riddled with fungal hyphae and eelworms. The whole consignment was unserviceable—and it consisted of beautiful four-bladed propellers for our newest and most powerful engine.

Another trouble was that new aeroplane wings sent from England arrived out with the internal cross-bracing wires slack. The fabric had to be cut open and the wires screwed taut. Before my arrival one had been sent home as an example, but on arrival it was reported as correct. The reason of this was that the higher temperature and lower humidity in Egypt resulted in the equilibrium moisture content of air dry wood decreasing—from around 13 to 9 or 8 per cent. Wings were accordingly sent out with openings for access.

Coming back to T.C.D. there were of course exceptionally large classes in botany; one was for serving soldiers, mainly from Scotch regiments. Their sound school education soon became apparent. Among the interesting lines developed during the lost years was that of W. Mansfield Clark and his collaborators on methods for the determination of hydrogen ion concentration, especially with his new sulphonephthalein indicators. A D.S.I.R. grant enabled me to buy these and to order a good potentiometer and galvanometer from U.S.A., as suitable ones were unobtainable here. Had the latter arrived promptly I don't think I could ever have accepted a post in the Imperial Dept. of Agriculture, India, to work on indigo at Pusa. But the fact that W. M. Davis of Rothamsted was there was a great attraction, as we had common interests on leaf carbohydrates. Though a friend described Pusa—in Bihar—as 'hot as hell and their wives frightful' I finally went. My stay was short, but highly educational, and Clark's book with its wonderful colour charts arrived soon after I did.

First of all I studied all aspects of the indigo crop and dye production and concluded that even with a plant giving a larger yield, indigo production would be uneconomic. Davis had already improved the yield of the 'mahai' (fermentation) and showed that a soil poor in nitrogen tended to give better development of the leguminous root nodules and had a higher indigo content. One great trouble was that in Bihar the plant produced little or no seed. This Davis attributed to phosphate deficiency, and Howard, the economic botanist, to poor soil aeration. A close study of the seed showed me that one could select those which would or would not germinate, the latter with approximate certainty, the former with high probability.

In 1919 Sir David Morris was president of Section K at Bournemouth and mentioned the very large areas in which Howard's Pusa 4 and Pusa 12 wheats were grown. The problem was—as Howard explained to me—to produce a good wheat that matured very rapidly, for it had to be planted when the soil was cold enough to reduce the activity of white ants and yet mature before the onset of the blasting hot winds from the Punjab.

Having Clark's colour chart and buffer tablets, I was able to use the sulphone phthalein indicators to determine the hydrogen ion concentrations of Indian soils and plant juices, which was then a new line of work.

My appointment at Plymouth was as Head of the (non-existent) Dept. of General Physiology at the Marine Biological Station with a biochemist, general physiologist and attendant as staff. The appointment of biochemist was never made. It was over six years before the building was up. But there was the lovely country and seaside, with Dartmoor inland. Following the American E. T. Wherry, the first paper on

the relation of the hydrogen ion concentration of the soil to the distribution of the British flora was published in 1921 and considered more adequately in papers, before the Royal Dublin Society that November, including one on the reaction of plant cells. The latter led to work on the flower colour of *Hydrangea hortensis*, W., and the availability of iron. Similar work on the distribution of snails resulted in measurements of the electrical conductivity of soil extracts (1925). From these came the knowledge that a soil of low conductivity, which remained low on standing for a week or more, was certainly very poor. A soil of moderate or high conductivity and showing an increase on standing was probably fair or good, but as this might be due merely to an unnecessary salinity one could not be sure. These conclusions were supported by the work of Sen and Wright at Rothamsted and in Nigeria on cotton soils. Work carried out with E. W. Fenton of Seale Hayne College dealt with the distribution of pasture plants and was finally published by the Royal Dublin Society in 1930, and in the Notes from the Botanical School of T.C.D. The observations had been extended to the Boghall Experimental Farm in Scotland when Fenton moved and were supplemented by persistence trials for six years in my garden in Cornwall. In the last named the outstanding feature was the persistence of *Medicago sativa*, lucerne, over the six years. In the cold dry spring of 1929 it gave a good stand about four inches high, before the other leguminous plants or grasses showed any very noticeable growth. It is thus useful in providing 'the early bit' for cattle or sheep. When allowed to roam sheep and cows will graze on most sites less acid than pH 5, which is the limit of *Trifolium repens*, wild white clover.

The Marine Biological Laboratory is, however, rather a misnomer for the institution to which I was appointed in February 1921. Though primary productivity in the sea depends upon plant life, the president was a zoologist and none of the twenty-one vice-presidents and governors were botanists. Out of fifteen members of council one was a botanist. The staff of seven were all zoologists and I was appointed, not as a botanist but as a general physiologist. But the position was not quite as bad as that, for three of the staff had an interest in the diatoms and peridinians. The Director, Dr. E. J. Allen, and E. W. Nelson, who had been on one of Scott's expeditions, worked on the culture of marine diatoms following the work of Miquel and of Richter upon fresh-water species. Also Dr. Marie V. Lebour extended her zoo-plankton work and published very useful handbooks *The Dinoflagellates of Northern Seas* (1925) and *The Planktonic Diatoms of Northern Seas* (1930). Now in 1958 the Governing Body still has only one botanist in the Council, and out of a staff of seventeen Dr. M. Parke is the only botanist.

Allen lived for the laboratory, and when in 1928 he edited the second edition of *Science of the Sea* (1912) he did so with a wide knowledge of the subject. Had he been less fettered by his constant dread that things might not be approved of by THE COUNCIL, the institution would have been both happier and more efficient. He was president of Section D at Hull in 1922 and his address on 'The Progression of Life in the Sea' was a clear presentation of fundamentals with interesting speculations on the origin of living matter and its primitive forms.

The lop-sided view of marine life, which neglects the primary source of production, was, however, peculiarly domiciled in the South of England, not shared by the Scandinavian nations or the Germans, who for long had studied the minute algal forms that float in the sea—the marine phytoplankton. The Germans too had studied the changes induced in the sea water by the abstraction of those elements required for plant nutrition, and D. J. Matthews, the hydrographer at Plymouth before the 1914 war, had begun work on phosphate removal.

As previously mentioned, I was interested in biological applications of the measurement of hydrogen ion concentration before coming to Plymouth, and there were obvious marine applications. The growth of the phytoplankton removed

carbon dioxide from the water. This was studied both by titrations and by colorimetric determinations of pH. An indication of the quantity of 'respirable carbon' could also be obtained by storing the tubes with the indicator used for pH determinations and noting the change in colour due to production of carbon dioxide. In conjunction with Harries, colorimetric determinations were made of the phosphate and silicate content of sea water. The phosphate determinations were made using the molybdate colorimetric method of Denigés, the silicate by that of Dièrert and Wandelbulcke. For nitrate the diphenylbenzidine method of Letts and Rae was found to be reliable, very sensitive and the colour stable towards light (1933, 1954 C).

Harvey has produced three very readable books on the chemical study of the fertility of sea water (1928, 1945, 1955). The importance of these chemical methods is enhanced by the possibility of using them to get a quantitative measurement of the phytoplankton crop. Benjamin Moore was the first to do this, with Prideaux and Herdman in 1915. Their result was rather too high, for they assumed that the change from winter to summer in the Irish Sea, pH 8·10 to pH 8·37, extended from top to bottom, whereas the measurements at E1 showed that the rise in alkalinity extends only to the well illuminated upper water layer, marked off by definite differences in temperature from late spring till about the end of September in our waters. This calculation was, however, a great advance as no such data had been used as a basis previously. My own value, based on the mean depth of the English Channel off Cornwall and taking carbohydrate produced as dextrose, amounted to one kilogram below each four metres of surface, or 250 metric tons per square kilometre as a minimum value between July and December 1921. Similar work on the uptake of other essential salts by the phytoplankton followed; nitrite from 1928; nitrate in 1931; copper 1931-32.

Dr. Allen kindly gave me some of a unialgal culture of the two-horned variety of *Phaeodactylum tricornutum* and it was found (1923) that the annual phosphate consumption could produce up to 30 million cells per litre. With various assumptions as to the composition of the diatom cell, it was calculated that, as a hexose sugar and for the 70 m. depth of water at E1, this represented 1·4 kg. of wet algal plankton under each square metre. In fact, however, as shown by Cooper (1938) there was a salt error in the phosphate estimation which, when corrected, raises the crop value as found from phosphate measurements to 1,920 tons for the year 1923, against Cooper's 1,360 metric tons per sq. km., down to 70 m. for 1931 when the winter phosphate maximum had been lower. Cooper also got 1,680 tons from the alkalinity change, 1,230 from nitrate consumption, 970 from oxygen consumption and only 112 from the silicate change. In view of the great insolubility of the frustules of many species of diatoms, a point tested directly by Miss Stanbury, it appeared probable (1945) that much of the consumption of phosphate and nitrate was due to the presence of very minute algae which were not retained by the finest bolting silk nets.

But going back to the 1923 work on phosphate, there was a marked difference between my results and those of Brandt (1920) and Raben (1916-20). The Germans found that phosphate was never entirely removed from the upper layers, whereas I found that with adequate illumination it could be. Matthews too found that certain treatments of the water resulted in an increased yield of phosphate which was attributed to the presence of organically bound phosphate. In 1924, however, I got one month's extra leave without pay to cover liability for service in the Reserve of Air Force Officers and family affairs. The money saved was used as an honorarium to get Miss E. G. Wilson, an old pupil and collaborator, who had succeeded me at the N.P.L., to come and work with me. She brought not only analytical skill but a knowledge of German far better than mine. She tackled the excellent papers of Raben, Brandt and other Germans, and we instituted a careful comparison of these

methods and our own (1926), for the analysis of compounds of phosphorus and silicon and showed that much of what the Germans thought was phosphate was arsenate (1927, with Wilson) and that at least part of what Matthews thought was phosphorus in organic combination was arsenic. The arsenic cycle was eventually investigated by Norris Rakestraw (1933), as was also the organic phosphate cycle by A. C. Redfield (1937) in U.S.A., and by Harvey (1948) at Plymouth. After the earlier work on arsenic I had studied its estimation and got excellent advice from the Home Office chemist. But as the council of zoologists knew better than I did how to use chemistry to study plant growth in the sea, I dropped chemistry; I let the new man tackle it and, save for completing the work on nitrate and copper, I continued with physical studies.

These studies, which had begun in 1924, consisted of measuring the illumination in the sea using photo-electric cells. I consulted my friend, Dr. H. H. Poole of the Royal Dublin Society, and he produced a very beautiful method, which was to measure the current by taking the drop in voltage across a high resistance circuit using a potentiometer, an amplifier, and a telephone as a null point indicator. Poole assembled it in Dublin early in 1924 and used it at Houth and that autumn near Plymouth.

With some modification I used Poole's apparatus (1925) till I left the M.B.A. in 1955. One could make up to six or eight measurements a minute, switching from the deck photometer to the submarine one and holding on to the gear by knees and elbows. It was used right through the winters. Ashore we tested and standardised photo cells (1935 RTA) and obtained records of illumination in air from December 1929 (1930) onwards (1936 RTA), having had a grant for a Cambridge Instrument Co. tread recorder, from the botanical committee of the Royal Society—help which has continued ever since and is most gratefully acknowledged.

For assistance in the arduous work at sea I am greatly indebted to Capt. Vivian Lord and his crew, on the *Oithona* first, but mainly on the *Salpa*, and after the war to Lieut.-Cdr. C. A. Hoodless, D.S.C., R.N.R., of the M.F.V. 1564 on charter from the Admiralty. The success of the work was largely due to their good judgement of the limits of safety, for none of the delicate apparatus was damaged, nor were the long hours of work ever grudged by their cheerful willing crews. Thanks are due also to Mr. F. J. Warren, who worked in the Dept. of General Physiology from boyhood till it was extinguished in 1955. His electrical knowledge and manipulative skill were of great value. Finally we had a few short trips in the M.V. *Sarsia*, specially built for marine research, but in some ways not at all as convenient for ours.

The work with a submarine photometer and one photo cell, covered by an opal disc set horizontally, was extended by the use of colour filters (1939 RTB) (1937 RPB) which showed that the green portion of the spectrum penetrated best in coastal waters, followed by the blue, the ultraviolet, the red, with the deep red very heavily absorbed. The early work was done from a wooden pier at Cawsand, in Plymouth Sound, where 'grew' a winch that served to lower the photometer. The promontory was thickly wooded, so it was possible to measure illumination inside and outside the wood, as we had long cables. It was soon evident that plant growth could best be correlated with 'the daylight factor', namely the ratio of the illumination at the site to that in an entirely open position on a cloudy day, or, failing that, when the sunlight was shaded from the open site photo cell. This work was continued elsewhere using portable galvanometers and four papers were contributed to the R. Dublin Soc. But where illumination is variable, and under rough water, one can use J. H. J. Poole's neon lamp (1928 D) photometer. In this the photo-electric current charges up one of a suitable series of condensers and the discharge of the latter through the lamp gives flashes at a rate adjustable by the condenser used. Unfortunately the use of a long cable at sea lessens sensitivity,

since the latter acts as a condenser. It was when using the neon lamp photometer in a wood that I understood Keats' lines.

Better even than the electrically determined daylight factor is the use of a spherical flask filled with a uranium oxalate mixture (1929 D). This decomposes in light setting free bubbles of gas. One can thus measure the light at a point, to which a small plant or a shrub may approximate compared with light in the open over a period of several hours, or one can study changes under water (1930). For these a more sensitive solution may be preferable.

For general use, however, there are small portable microammeters and selenium rectifier cells. The best may show a rectilinear relation between current and illumination up to one or even four microamperes and have a spectral sensitivity curve reasonably near that of the human eye, though that is no special advantage for the study of plant growth. It is essential to mount them below opal diffusing glass and to cut down the illumination to well within the region of rectilinearity. This tends to diminish, especially if the cell is exposed to damp air. The constancy of such cells cannot be relied on and frequent checks against cells of the vacuum type are essential. Unlike the latter, the rectifier cells work without a H.T. battery. Using these cells, daylight factors were determined in Devon woods of spruce, larch, oak and holm oak (1930 D) and later colour factors were obtained to compare the composition of daylight in the open and in shaded situations, taking as unity the readings for blue, green yellow and red under a grey sky (1931 D).

Here may be mentioned a beautiful series of experiments carried out near Plymouth by Miss P. M. Jenkin (1937). She exposed sets of unialgal cultures of *Coscinodiscus excentricus* at various depths and at different hours, and measured the oxygen production allowing for respiration in dark control vessels. The production was correlated with the intensity of the illumination and showed clearly the loss of efficiency when the intensity is too great as at small depths of immersion in the middle of the day. On the large scale such effects may be seen off S. Georgia as shown in reports of the Discovery Expedition. On the north side impact against the coast causes upwelling and the phosphate rich water is subjected to good daylight so that the diatoms multiply. Numerous copepods thrive on these and with the larger Emphausids are the main food of species of whale. Much the same upwelling accounts for the good fishing near Iceland.

The work at sea was carried out if possible once a fortnight, and measurements of the extinction coefficient were compared with values of the depth in metres to which a white 'Secchi' disc, 20 cm. in diameter, could be seen. The variation with size of disc was also studied. It is now well established that the main cause of high extinction coefficients in the open sea is the presence of suspended plant cells or their debris (1954, with Jenkins and Warren). This has been confirmed by measurements of chlorophyll concentration and of the extinction in a tube about a metre long fitted up to a Pulfrick photometer. The effect of light scattering is more marked in the tube than in the sea for which special measurements have been made using a flask with photo-multiplier cell and a high sensitivity galvanometer. The scattering was found to be predominantly forward (1952 R, 1954 D).

A cube photometer (1940) was also constructed, having six rectifier cells. One could thus measure the ratio of upward scattered light to that coming downwards. This for clear water is about 2 per cent and is an important measurement, in relation to the depth of visibility of a submarine. It was found from the readings of all six cells that the ratio of total light received at a point to the vertical illumination in water never differed much from 1·25, the angle of obliquity with the vertical being 30°–40°. In air the ratio is unlikely to be less than 1·5 and may run up to 5 or 6 with low sun (1958 C).

Meanwhile, the work on the consumption of essential salts, upon sea temperatures, and light transmission was being carried on with but little attempt at

following the seasonal production or distribution of the phytoplankton. Valuable work was, however, done in the Scottish laboratory at Millport by Marshall and Orr (1928, 1930) and at the Ministry of Fisheries laboratories at Lowestoft by Wimpenny (1936, 1944, 1946) and later by Corlett (1953 C) on diatoms and at Burnham-on-Crouch by Butcher on the flagellates. At Plymouth Lebour looked at tow-nettings, but kept no records of the occurrences even of Phaeocystis.

Though a botanist—and the only one—those subsequently engaged were not under my control, I could get no assistance in work on the phytoplankton, laborious and severe on old eyes. I did, however, get in 1947 a secondary school girl of seventeen, Miss P. G. Jenkins, as a laboratory assistant and trained her in microscopy and identification of the phytoplankton. For one thing, I wanted to know whether the much smaller crop calculated from the silicate changes could be explained by an unsuspectedly great amount of non-siliceous species as I had previously suggested (1945). Since then Harvey's results (1950) and our own showed that the finest bolting silk (40 $\mu \times 50$ μ) does let much through. Knight-Jones and Walne too (1951) have shown that *Chromulina pusilla* Butcher can be abundant in creeks and in the open sea, though the minute size of this chrysomonad, 1·5 μ, is against its being a major constituent by bulk of the plankton. At Cronulla Ferguson Wood (1955 C, a and b) has perfected methods of fluorescent microscopy that can detect autotrophic flagellates down to 1 μ in length. Working with Davis (1956) he has shown that the chlorophyll content of the organisms retained by filtration through the finest silk net was far less than that of the cells collected when the water was spun in a continuous centrifuge, the latter being 25 to 3,000 times as great, while counts of the minute organisms are 10 to 100 times as great again. No determinations were made during diatom blooms. Again, in the Florida current off Miami, Miller and Moore (1953) took samples for a year and compared finest silk net samples with those got by filtration through a No. 54 Whatman paper. The pigment concentrations were compared using Harvey's solution. The yields from the paper were about 1,000 times as great as when silk was used.

In Harvey's valuable work (1935) on phytoplankton production, use was made of the chlorophyll extraction method introduced by Kreps and Verjbinskaya (1930 C), a brownish green solution having been concocted by Harvey to match the colour. To do this I had got a crystalline chlorophyll, but, finding Harvey was on Krep's line, I left it to him. Later, however, Dr. Parke provided me with twelve pure cultures of diatoms and non-siliceous plankton species; she counted the numbers in unit volume from which we (1951) were able to ascertain the number of individuals per milligram of chlorophyll. For this we used an ordinary colorimeter with a red filter which transmitted freely the chlorophyll absorption bands above 0·6 μ. The advent of a Unicam spectrophotometer, however, provided the ideal method of following changes in the phytoplankton by measurement of the transmission right through the chlorophyll spectrum, and more especially the determination of the absorption at the maximum for chlorophyll *a* (Atkins and Jenkins, 1953). The work was continued by Jenkins (1955) and in further joint work use was made of chromatographically pure chlorophyll *a* and of extracts from Parke's pure cultures which gave an identical maximum of absorption at 666 mμ. Together with the spectrophotometric measurements, we carefully examined the phytoplankton obtained from nine or ten samples 5 to 10 m. apart from 0–70 m. at station E1 throughout three years. This was done using a bacteriological culture method. Samples of water, 100 or 200 ml., were enriched with Miquel solutions and exposed to diffuse daylight. In the identifications we are grateful for the generous help of Dr. M. V. Lebour, Dr. M. Parke and Dr. T. J. Hart, who were then working in the laboratory. All the difficult Fragilarias were checked by Hart and several unidentifiable microflagellates were handed to Dr. Parke for attempted culture.

The non-siliceous algae found belonged to the Chlorophyceae, Chrysophyceae,

and Cryptophyceae and very rarely Cyanophyceae. Frequent but not numerous were Coccophoridaceae. Most numerous were the Bacillariales, save that sometimes the non-siliceous *Phaeocystis globosa*, one of the Chrysophyceae, was present in great quantity though in some years it was entirely absent. Between September 1951 and July 1954 we found 67 diatoms at E1, including 8 in which the genus only was determined. The totals were 51, 45 and 39 for the years 1952, 1953 and up to June 1954. These years had in all only 39 of those found by Lebour inside the Eddystone in 1934. It is instructive to divide these diatom species into oceanic, neritic and tychopelagic and to express the results as the ratio of the oceanic to the sum of the other two, the tychopelagic being but few. The 1928 value is based on Lebour's findings in nets at E1. Algae named by genus only could not be grouped for the ratio.

TABLE I

Ratio of oceanic to other diatoms

Year	Jan.-June	July-Dec.
1928	0·53	—
1934	0·37	0·36
1952	0·00	0·31
1953	0·18	0·32
1954	0·77	—

It should be appreciated that the distinction between oceanic and neritic species is difficult, I have accepted Prof. Gran's decisions on this. It appears to depend upon whether or not a diatom can remain floating throughout the year, or whether at some stage it must sink to the bottom. For such matters observations made on the Weather Ships should prove most valuable and we shall shortly hear Mr. Corlett on this and Mr. Wimpenny on the change in volume undergone by rapidly multiplying diatoms—for determinations of chlorophyll show no such vast increases as are shown by counts. The usually high ratio of the oceanic in 1954 must indicate a movement of oceanic water in to E1. This is fully supported by the results of routine chemical methods for the period in question.

When in 1923 a systematic survey of the seasonal variation in phosphate was begun, it soon became clear that the time of the diatom outburst, as indicated by phosphate consumption, might vary by eight or ten weeks. The delays in the spring outburst were sometimes puzzling, for the increase in daylight seemed adequate. Various workers of distinction suggested that some minor constituent of the water was still missing, but this seemed unlikely, as it was early in the year and complete regeneration of phosphate, and presumably of other constituents, had just occurred. However, a lag in phosphate consumption, well beyond that expected from the illumination, was a mathematical necessity, for only after repeated cell divisions could the phosphate consumption come within the limit detectable by our most sensitive methods. Once detectable, repeated doublings in consumption soon led to exhaustion. There were, however, other questions behind this—how great had been the winter reduction in the stock of diatoms? Multiplication of a smaller stock required, of necessity, a longer period to become perceptible. There might be an inflow of a water mass with a lower population, but against this was a uniform phosphate content and a uniform salinity over an area in which meteorological conditions were reasonably constant. We finally approached the problem through the neglected study of the algal cells themselves. We came across a year, 1954, in which the low chlorophyll yield found in January was followed by a higher yield in February. But the March value was one-third of that of January. At first it

seemed impossible, but phosphate determinations in 1925 had indicated very similar late development. The routine phosphate and silicate determinations were at this period made by Armstrong and, as always, the salinity by the Government chemist. Neither temperature nor salinity suggested that the water mass at our station, E1, was in February or March appreciably different from what it had been in January. Both pointed to close similarity, as did the phosphate which perhaps even rose very slightly in February. But the silicate analyses were startling; from February on they were at a much lower level having fallen from 4·70 to 2·83 milligram atoms of silicon per cubic metre. This, unaccompanied by a fall in phosphate, was clear proof that we had to deal with a different mass of water, in which the chlorophyll content indicated a sparse plankton and the cultures showed an unusually high ratio of oceanic species. Thus, after thirty years at least one good reason for the lateness of the phytoplankton crop had become evident. This does not, however, demonstrate that mere changes in the vertical circulation may not be important in other years.

As stated, chlorophyll determinations were made at intervals from surface to bottom for three years. A very abbreviated summary of these is given in Table II showing the results reduced to milligrams per cubic metre for chloryphyll *a*.

TABLE II

Chlorophyll in the water column at station E1, shown as mg/m³.

	1951	1952	1953	1954
Jan.	–	4	4	6
March	–	17	25	2
Apr.-May	–	19	46–52	4–13
June	–	2	5	4
Sept.-Oct.	14	8	10–13	–
Nov.-Dec.	4	5	4	–

The uniformity of the values for the winter minimum is very striking, as is also the similarity of the summer minimum in June, brought about by exhaustion of mineral nutrients. The chlorophyll determinations showed precisely where in the water column the phytoplankton cells were located at any time, whereas the phosphate analyses gave a value integrated over a considerable period. The identification of the species responsible for the various developments raised many questions as yet unanswered. The detailed results are too cumbersome to be given here. We did not take counts—and counts are not a measure of weighable quantity—but we did ascertain when different species were most abundant.

The phosphate estimation, begun in 1923, is still being made and the results may be summarised in groups as follows.

TABLE III

Year Group	Winter maximum	Percentage used 0–20 m.	Percentage used 0–70 m.	Amount used as percentage of first group
1923–1929	100	93·6	77·4	100
1931–1938	67·3	93·1	78·2	69
1948	75·4	99·0	91·5	89
1950–1956	72·9	83·9	65·6	62

The second column gives the value of the first group as 100 per cent for the January maximum which was actually 69 milligram atoms of phosphorus per 100 cubic metres, the volume being chosen to avoid decimals. Three other year groups follow. The third column gives the percentage of the available phosphate used in the upper well-lighted 20 metres, and the fourth that used in the whole 70 m. column. The last column shows the weight used up as a percentage of that available in the first year group, namely it shows the relative production for the groups. It may be seen that the upper 20 m. phosphate was well used up, but, owing to some years being calmer than others, the deeper water remained comparatively cut off from the upper, so its phosphate was not available to the same extent. In recent years Cooper has put forward a theory of oceanic circulation which may account for the observed decrease in the winter phosphate maximum shown in the second column.

Soon after coming to Plymouth, I realised how serious were the losses in nets and ropes, and, having had experience in Egypt of the decay of various fabrics, I began work. The first paper (1923) showed what methods were useless. The second (1925) introduced copper oleate for both our silk plankton nets and the large stramin nets. Olie's method, cutch and ammonical copper sulphate, was also used for the latter. By 1928 the Danish 'Cuprinol' had been shown to be very effective and to be a copper soap of a naphtenic acid (or acids) derived from petroleum. Further extensive tests (1936) showed its great value for ropes, the cheaper Dutch method (Olie's) being adequate for nets. By request of the Admiralty anti-fouling preservative greases were also prepared for sea mines, to prolong their period of effectiveness and to ensure the correct operation of the safety device if adrift. After prolonged tests on a raft at Plymouth one was adopted and became the standard issue, used on our mines in the recent war.

When war came our laboratory sand-bags were immediately treated with the residues of our tested preservatives. A Sandbags Committee of the Ministry of Home Security was started after 155 million bags had rotted untreated. But an English firm, 'The National Smelting Company', had begun to make Cuprinol about seven years before the war and 22 million bags were preserved with Cuprinol and creosote, a mixture too messy and too inflammable to be appreciated in the Army. I was on the Committee that decided to adopt Olie's method, treating with ammoniacal copper sulphate only; the proofers were paid one farthing a bag, the work being done in India. The cost was about 10 per cent of the lighter weight bags and during the war 187 million bags were thus treated, the life of a bag being prolonged up to about two years when used in England.

But a botanist may have public duties outside the scope of his own work. In 1954 I had one such peremptory call. I read of the coming eviction of Mr. George Benney from his farm at Constantine in Cornwall. I visited him, saw his land and realized the injustice he was suffering. His grandfather had bought the farm. His father worked it and he had spent his whole life on it. The inspectors had not even measured the depth of soil on this upland wind-swept holding. They had not tested the soil or examined the herbage. I did these things and consulted the large-scale maps and the Memoirs of the Geological Survey. Though there was much good land in the area a farm partly on granite and partly on a poor quality shale is at a great disadvantage. I reported the facts to the *Cornish Times* and with the details to the Ministry of Agriculture. My letters were published by the paper and acknowledged by the Ministry. On a point of law Benney won his final appeal, but, as he told me in a letter, 'our legal expenses amounted to £590 and during the four years that we were farming under their (the C.A.E.C.) dictatorship we lost money'. I am truly glad that at last and belatedly, Government action has removed from our farmers the risk of such injustices.

References

For brevity references in text given as (say) 1928 refer to *J. Marine Biol. Assoc.*, name of author being given unless Atkins or Poole and Atkins. Similarly papers in *Sci. Proc. R. Dublin Soc.* are shown as 1928 D, those in *J. Cons. Internat. Expl. Mer.* go as 1928 C, in the Royal Society as 1928 R, adding P Proc. or T Trans., and A or B for series as usual.

Atkins, W. R. G. (1924): *J. Agric. Sci.*
Atkins, W. R. G. (1945): *Nature*, **156.**
Atkins, W. R. G. (1950): *Internat. Bot. Congr.*
Atkins, W. R. G. & Poole, H. H. (1930): *Nature*, **125,** 305.
Atkins, W. R. G. & Wilson, E. G. (1926): *Biochem. J.*
Brandt, K. (1920): 3 *Abh. Wiss Meeresuntersuch. Att. Kiel*, **18,** 185-430.
Denigès, G. (1921): *C. R. Soc. Biol. Paris*, 84.
Jenkins, P. G. (1955): *The Bigelow Volume.*
Jorgensen, E. G. (1952): *Physiol. Plantarum*, **5.**
—— (1953): *loc. cit.* **6.**
—— (1955); *loc. cit.* **8,** 840 and 846.
Jorgensen, E. G. (1957): *Dansk Bot. Arkiv.* 18.
Knight-Jones, E. W. & Walne, P. R. (1951): *Nature*, **167.**
Miller, S. M. & Moore, H. B. (1953): *Nature*, **171.**
Moore B., Prideaux, E. B. R. & Herdman, G. A. (1915): *Proc. & Trans. Liverpool Biol. Soc.* **29,** 233-64.
Pearsall, W. H. & Priestley, J. H. (1923), *New Physiologist*, **22,** 185-191.
Poole, H. H. (1925): *Sci. Proc. R. Dub. Soc.*
Poole, J. H. J. (1928): *loc. cit.*
Raben, E. (1916-20): *Wiss. Meeresuntersuch.*, **18,** 1-24.
Redfield, A. C. Smith, H. P. & Ketchum, B. (1957): *Biol. Bull. Woods Hole*, **73.**
Rakestraw, N. W. & Lutz, F. B. (1933), *loc. cit.*, **65.**
Wood, E. J., Ferguson & Davis, F. S. (1956): *Nature*, **177.**

WHAT ARE OUR SCHOOLS FOR?[1]

ADDRESS BY SIR JAMES J. ROBERTSON, O.B.E.

PRESIDENT OF SECTION L

ADDRESSING heads of schools last winter, one of the Scottish law-lords revealed that, whereas in 1949 Scotland could provide each prisoner with 'a suite of cells', today we had two or three prisoners in each cell; and he went on to argue that in face of the stark facts of crime we could not claim that our educational system was fulfilling its proper function. He freely admitted the need for more teachers and smaller classes, but urged revision of curriculum now, even at the price of lowering the standards of technical education, being convinced that any loss would be more than made up in 'the better calibre of the pupil produced, both in his application and use of the knowledge acquired and in his attitude and contribution to society'.

The *Scottish Educational Journal* at once leapt to the defence. Church and School were fighting with inadequate support a rearguard action against vicious influences at work around them. With classrooms overcrowded and understaffed, small wonder if the moral lessons taught had little permanence.

About the same time, Mr. R. A. Butler, speaking on the increase of crime, said there was an immense task to be done by the schools in regard to 'moral obligations, pride in integrity and respect for the rights of others'. In this regard only, had he felt considerable disappointment after the vast amount of time and money the Government and the local authorities had spent on education.

The Times Educational Supplement promptly commented that the Home Secretary had 'let slip a remark on the schools which he might wish to reconsider. No doubt the schools could carry out their task of moral persuasion better than they do. But it is surely wrong to imply that they are not doing their best', in face of 'difficulties caused by confusion in the world outside'.

These two expressions of disquiet and the immediate rejoinders they called forth seem to crystallise much of the current bewilderment about the functions of the schools in face of the ever-deepening moral and social confusion of our time. Regarded primarily as attributions of blame to the schools, such criticisms are easily rebutted: but surely their real significance is as troubled expressions of the collective conscience over the alarming insufficiency of society's agencies for securing its own health and progress.

At Glasgow last September, in a very brief tailpiece to a paper on technical education, I argued that we are indeed neglecting the greater task of education for the lesser, though not unimportant, task of instruction, and to that same theme I return with a less hurried approach this morning.

We all know what our schools are for—the nurture of the nation's young. The answer is formally correct, and at the theoretical level we find sweet accord about impeccable aims; for nurture means not skills and knowledge alone but the quickening and exercise of intelligence, coupled with due attention to the physical, moral, and affective alike, in the shaping not of the future worker only but of the human person and the citizen. But to turn to the schools is, alas, to experience a painful sense of shrinkage and lost vision within a day-to-day practice which belies our lofty professions and seems to mock our national predicament.

At the outset, however, we must resolutely guard against two errors. First, we must not panic and demand of the schools more than they could give, even if they

[1] Address delivered to Section L (Education) on Friday, September 4, 1959, at the York Meeting of the British Association.

were residential, and not in fact limited in their control of the children to some 1,200 hours a year. Many agencies shape the lives of youth, and, if I may quote words I penned years ago, 'It is a dangerous assumption that the school can be a ready substitute where some of these influences fail and a sufficient antidote where others become potent for evil. . . . There is no alchemy by which education can transmute into fine gold the base metal of a distracted and materially-minded age.' Let us be clear, then, that what gives cause for disquiet is not the schools' failure to accept an almost total responsibility for individual and social well-being: it is that in this field of their duties they are not making the contribution they might make, were they less engrossed (or should we say, were they *allowed* to be less engrossed?) in other things which on a just assessment are of less account. And second, we must refrain from seeking a scapegoat for our national ills. We are all in this together, and of the curious assortment of utensils that adorn the educational stove none is in a position to call the others black. Furthermore, if I voice this morning certain criticisms of the system I have served, it is not as any kind of expert—and least of all as one stepping down from his ivory tower—but simply as a teacher responsible these thirty-three years past for the direction of combined primary and secondary schools, and at the end of it feeling very conscious of the things left undone. Not that the things done are unimportant or that those who do them fail to merit our esteem. On the contrary, I leave teaching with immense respect for grammar-school colleagues on both sides of the border. In the past half-century they have done a transforming work, while in scholarship, sustained keenness, and competence in the task allotted them, they will stand comparison with any professional group in the country. Even livelier perhaps must be our admiration for what your secondary modern and our junior secondary staffs have accomplished in face of conditions often depressing in the extreme and difficulties calculated to daunt all but the stoutest hearts.

And yet the doubt persists: are we, time and men's energies being limited, using these capable and devoted people in the best interests of our land? The Prime Minister says they have never had it so good. But who are these favoured *they*, the proud heirs of a democratic, Christian way of life that sets them apart from the hapless instruments of totalitarianism? Have they the inner resources which in the past gave dignity and worth to simple lives? Are they capable of wedding responsibility with freedom, of showing true tolerance, of subordinating personal advantage to the common interest and looking beyond their selfish noses at a world in need? In short, are they within distance of being able to work that real democracy, of which Middleton Murry finely said that 'it is the beginning not the end of travail'.

The Scottish law-lord and the Home Secretary were rightly worried about full gaols. Are full mental hospitals any less disturbing? Or empty heads and lives and church pews and ballot-boxes? The waning respect for parliament and the growing indifference to the processes of local government are ominous signs. An essentially lovable young generation is adrift in bewilderment and blindly irrational revolt, while the unhappy faces of their elders all too often mirror hearts not at peace. One thing seems to unite us all—the scramble for largely worthless money, to spend on largely needless things. The Arts may languish and be starved, but the Pools prosper and imbecile entertainment can command its price. Again, are we politically mature? Reflect on the fate of any party that should invite us to forgo luxury for a decade and devote, say, a thousand millions a year to developing India and the African territories. Nay, would we save it for ourselves, let alone for others? Contrasting our White Paper with the Russian Educational Budget, *The Times Educational Supplement* wrote, 'What government would restrict the production of consumer goods—the pretty dresses, the battling detergents, and all the fripperies of our rich lives—and put the saved resources into educational preparation

for the future? Our government cannot require such austerity: we would not have it.' If that is democracy, it is 'beat' democracy.

It frets me to obtrude these depressing reminders, but they are the only medicine I know for an educational smugness which fixes its gaze on the well-ordered plot it cultivates and ignores the wilderness beyond. If you say that for any measurable time to come strategic and economic necessity will determine the functions of our schools and that, to be honest, comfort not democracy is what we are after, there is little left to argue about; but if we still acknowledge exacting social and spiritual obligations, then I hold that, with the exception of our enlightened infant departments, there is no part of our educational system in respect of which our present complacency is justified and little in our current practice which does not call for a close and critical scrutiny.

Let us begin that scrutiny at the top end, in the grammar school; and, since there is talk in more than one quarter of segregating the high flyers, be they five per cent or eight, from an early age, we may start with them. For such our academic education was designed, and, given certain safeguards, they are not ill-served by it, in the sense that they are capable of covering the syllabuses at high level without excessive strain. Nor are they unduly disturbed by the examination ordeal, which in any event they will have to face again and again in their university or college years. But all that is no more than to say that with them the grammar school succeeds in what it sets out to do, namely to give them a rigorous intellectual training, with heavy demands on memory, and to equip them for the time being at least with a big store of factual knowledge. It remains to ask, however, even of their purely intellectual outfit, whether we have allowed time for it to become part of themselves, so that it will be a source of strength and satisfaction to them down the years and not simply the instrument of their careers-ambitions. And the answer cannot be a wholly confident yes, for it is common knowledge that the universities are critical of the products of the schools, alleging that ability to think and to express is in danger of being subordinated to the accumulation of facts. Indeed, a spring issue of *The Times Educational Supplement* carried a letter, signed by three of the examiners in the Final Honours School of English at Oxford, in which they passed severe strictures on the work of all but a very few of the best candidates, finding it flawed by pitiably weak vocabulary, irrelevance, feeble and limited sentence-structure, and inadequacy in both width and depth of reading.

'If gold ruste, what shal iren do?'

Again, what have we done for these highly-gifted pupils in the course of their strenuous scholastic race to quicken sensibility or nourish imagination, or what share in co-operative activity have we made possible for them, to correct even a little their youthful sense of self-sufficiency and awaken them to their 'need of a world of men'? 'The greatest danger', writes H. A. Rée, 'is that we may be producing a class that is exclusively concerned with its own well-being.' Do we not increase that risk, if we concentrate these high-powered youngsters in separate schools from the age of eleven onwards? They may well, at the end of the day, give Winchester and Manchester Grammar a fright, if that be deemed a praiseworthy ambition. But as these flyers emerge increasingly from homes lacking alike firm cultural standards and any accepted tradition of public service, the greater will be the danger of throwing up a tribe of Lucky Jims, or even worse, a self-appointed élite viewing their less-gifted fellows as little more than the instruments of their superior purposes, and showing themselves, in Belloc's phrase, 'as full of pride as minor devils'. Should we spare a thought for those who will have to teach such 'fizzers' unbrokenly? As the exile, under endless tropic sunshine, reaches the point when he would almost barter his hopes of a C.M.G. for one good Scotch mist or a day of rain, may not these others come to sigh for the restoring presence

of a few quite ordinary tousle-heads in all their heedlessness and stupidity? But I digress! Let us pass from the flyers to the much larger group, broadly those within the second and third tenths of the intelligence scale, who form the main clientele of the English and Scottish grammar schools. These are the much-envied, the supposedly fortunate, and yet it is my sober judgment after forty years among them that they are, in the strictly educational sense, the worst-used children in contemporary Britain. Do not misunderstand me. They are in the main taught in good and well-equipped buildings by graduate teachers of character and ability, nor do they as a rule lack adequate provision for games and extra-curricular activities, privileges that no sane person would lightly dismiss. But the central realities of their school-existence are a curriculum too heavily loaded and exacting for most of them, and an external examination in which a full measure of success is accorded only to a minority. Statistics must be used with caution here, but Vernon tells us that in a favoured area with a grammar-school intake of under 30 per cent, less than a third secure five or more G.C.E. passes; about a third get one to four passes, and one-third do not reach the certificate at all. With allowance for the differences in the examination systems of the two countries, the Scottish position is very similar. But the charge against the existing education in grammar schools goes far beyond the proportion of passes and failures. It rests on (1) the excessive demands made on growing boys and girls, (2) the deplorably low level of real attainment, (3) the unassimilated and consequently impermanent nature of the knowledge acquired, and (4) the obsessional concern with examinations, leading to distorted teaching of what is to be examined and neglect of what is not.

To have youngsters in school from nine to four with only a lunch break, and then to require nightly preparation ranging from 1½ hours of the twelve-year-old up to a figure we are coy of mentioning, as the examination draws near, is to make demands at once excessive and, if conceded, fatal to both the pupils' unhurried pursuit of personal interests and their healthy participation in the social activities of home or neighbourhood. Mercifully, the sound instincts of youth rebel against such monopolistic claims and all but a few successfully take evading action, but the price is paid in the shockingly low standards of performance. It is common knowledge what a big proportion of passes always cluster near the pass-mark, and which of us is unfamiliar with what a 50 per cent paper means—the scraping of odd marks for this and that, the abysses of ignorance or muddle revealed or hinted at, and over it all the unmistakable evidence that too much has been attempted and too fast. But these, after all, are passes: over the thirty-five and forty per-centers and the travesty of schooling their performance represents, it is better to draw the veil.

That skills and knowledge acquired under such conditions go swiftly down the wind is evidenced time and again by the comments of our average secondary-school products on the end result of it all. 'We forget our lessons but remember our Masters', says many an Old Boy at the Annual Dinner. The references to us and our idiosyncrasies are kindly meant, but such pronouncements, however exaggerated, reflect badly on our educational system, for they come near to saying that what we have really secured for our young people, at the sacrifice of much else, is just a rather bigger stock of easily-producible knowledge at certain points in later adolescence, knowledge which ten or fifteen years later has vanished away.

To state the truth about the tyranny of the examination is always to be charged with gross exaggeration: yet the facts are not really in dispute. The exalting of memory and rote-learning at the expense of understanding and curiosity is as little open to question as is the starving of the non-examinables and the filching or misuse of even the scraps of time we allocate to them. The examination and the careers it leads to are always with us. That is what parents come to talk to us about and boys assume to be the object of the exercise. Successful in this, a school is

invulnerable, and the doors of promotion open to its staff. Again, how do we assess the validity of selection procedures? By their correlation with success in G.C.E. or Scottish Leaving Certificate. Why not? Who is going to object? Dr. Mary Clarke, the distinguished Former Head of Manchester High School, recently wrote, 'According to the schoolchild's scale of values, no subject which does not "count in examinations" is of much importance, and the more intelligent the child, the stronger is, as a rule, his conviction on this point.' Lastly, let me record that almost the only parent who in my recollection ever sought to invoke the Conscience Clause wanted his boy to have the Scripture periods for extra mathematics. He had a conscience, he had, about wasting time!

Within this tragi-comedy of the examination-cultus, we have the spectacle of one occupational group after another straining after status by demanding more of its young entrants; and so, in defiance of Hartog, Rhodes and all the tribe of unbelievers, they join with the academics and the older professions in according to the near-infallibility of the external examination that simple faith which, the poet has it, is more than Norman blood.

All this is the more grievous because a brief moment of sanity was vouchsafed to us. Your Norwood Committee and a little later the Scottish Advisory Council found in favour of a secondary schooling undisturbed by any external examination before the age of seventeen or eighteen. The sequel reflects not their failure in argument but ours in vision and social purpose.

> 'The shaken mists a space unsettled, then
> Round the half-glimpsed turrets slowly washed again.'

'Their future is their own to make' were the brave words of *Educational Reconstruction, 1943*, and many of us north of the border, recalling how much the old senior schools in England had accomplished, looked with quickened interest and expectancy to the new secondary modern schools, with their charter of freedom to let the education they provided develop 'out of the interest of the children'. We knew, of course, about the many ill-equipped and depressing buildings. We remembered that the new challenge had to be met in the main by teachers trained in the old elementary tradition. But we dared to hope that out of the tragedy of a Second World War there would come to many, as it had come to George Sampson out of the earlier calamity, a tender awareness that what ordinary children need most of all is neither this skill nor that smattering but just to be humanised and helped even a little way towards civilised living.

Fifteen years after, it is a strangely chequered story we read, how chequered we had perhaps hardly realised, until we had Professor Dent's admirably fair survey. By a most natural development, the secondary moderns turned to 'projects' and 'centres of interest', largely subordinating to them other forms of teaching. And some succeeded almost beyond praise; and others did not, but fell into varying degrees of muddle, imitative routine and shoddy work, a result not difficult to foresee. Did a country which had allowed generations for the evolving of the techniques of class-teaching show patience and encouragement towards the immensely difficult task that was being essayed? Not a bit. Within five or six years, Dent tells us, external pressures brought to bear on the modern schools resulted in 'a widespread trend away from unconventional to more conventional approaches and methods'. Standards, you see, were in danger. Now, this failure of nerve can only be regarded as disastrous, for if ever there was a case where a particular stage had to be gone through and got over somewhere, somehow, somewhen, it was in this breakaway from subject teaching into an activity curriculum in the education of average pupils. Admittedly, you cannot experiment with children precisely as you do with chemicals or even with guinea-pigs, but the human young has survived far worse things than an over-sudden and insufficiently planned venture into Deweyism.

Experience would have rectified most of what was amiss, and it should have been evident enough that there were but two main remedies for the recalcitrant idleness of ordinary children in face of a largely book-based curriculum; recourse to forms of group-activity and the fullest utilisation of the vocational interest, provided always that the practical work undertaken satisfied Duncan of Lankhills' test of educational value, namely that it should express a purpose and not simply show a result.

It profits nothing to tear a passion to tatters over the invasion of the secondary modern school by G.C.E. and other examinations: educationally it is folly, but by other criteria amply justified. A country socially stratified and sunk in a kindly materialism acts on the assumption that certain careers are supremely worth striving for, and that some such examination as G.C.E. is the appropriate passport to these careers. If, then, the chance to secure this precious bit of paper is about the greatest boon we can confer on ambitious youth and admission to grammar schools is on a competitive not a qualifying basis, how can any fair-minded man contest Professor Dent's verdict that 'children in secondary modern schools who appear capable of securing G.C.E. passes have the right to require that they be prepared for the examination'? What is important here is to recognise that we have passed completely out of the world of educational values. I am prepared, on a lifetime's experience, to maintain that, while a smallish proportion of parents of cultivated mind may seek and value the traditional schooling for its own sake, not one middle- or working-class parent in twenty seriously cares what else the grammar school does with his or her offspring, so long as it disciplines reasonably and delivers the goods at the end of the day. Small wonder then if the secondary modern is itself setting up in business, with the blessing of a Minister of Education not a little shaken by the onslaught on eleven-plus. We are, of course, up to much the same tricks in Scotland. But, while there must be no self-righteous reproaches cast at either parents or schoolmasters, those of us who believe that the secondary modern school has at once a high responsibility and a great chance must align ourselves with the sober protests made by Dr. Joseph Hill of Loughborough and others that so much should be sacrificed for so little—an average per candidate of four G.C.E. Ordinary level subjects attempted and two passed. Professor Dent is fully alive to the meaning of a situation in which one secondary modern in six has already embarked on G.C.E. work and warns that such courses contain within themselves the greatest danger that could threaten the future of the secondary modern school—'the danger that its main efforts might be directed from its central task, the general education of the ordinary child'.

Many Heads, of course, have not capitulated, and it lifts the heart to read such an account as Mr. Kneebone gives of Beckfield County Secondary Modern School, and not least his brief, restrained statement of the cogent reasons why he will have none of G.C.E. Before leaving this disturbing theme, may I remark that, while the substitution of regional or local tests with advisory assessors may temper the ill-effects of the orthodox external examination, it cannot wholly escape them, nor does Mr. C. D. Butler of Exeter set one at ease by the comforting assurance in regard to a Devon scheme, that, 'in fact, it boils down to something little different from the ordinary end of term exam.' For the question still nags: if we were dealing with these secondary modern pupils according to our best lights, would there, in fact, be any end-of-term exams, as we have known them?

If so much of the morning glory of the secondary modern has faded by noonday, what shall we say of the primary school? It too had a gallant prospectus, culled from *Educational Reconstruction, 1943.* The special place examination was to go, and 'other arrangements for the classification of children when they passed from primary to secondary school' would exorcise the evils of the competitive test and help the schools to foster 'the potentialities of children at an age when their minds are nimble and receptive, their curiosity strong, their imagination fertile and their

spirits high'. This surely was to serve notice on 'the barbarous simplicity', as Nunn called it, and the almost unrelieved passivity of class-teaching, and to usher in a flexibility of method, within which there would be place certainly for the good and lively class-lesson, but varied and supplemented by much child-centred activity both individual and group. In a word, the schools were to make these irreplaceable years of childhood a natural sequel to the kindergarten, a bit of real living and not primarily a preparation for anything. It was not to be. One of the achievements of our time has been to extend to the working and lower middle-classes the blessing long enjoyed by 'their betters', of continual striving for social and economic status. Universal careerism, paper qualifications for almost every job a neighbour of the Joneses could possibly look at, and the grammar school as the way up—these are the educational facts of life in the 1950's, and they lead straight back to a primary schooling geared to eleven-plus, with tests and streaming at seven, tests again at nine, and all the pressures that make short work of educational frills and experiments.

The wrong suffered by the primary school is not confined, however, to this distortion of its function, in order to further our worldly ambitions. The excessive size of primary classes alone almost precludes enlightened methods and compels a high concentration on the basic skills; and now, when the passing of the population bulge into the secondary school might have given the primaries some slight relief and the possibility of at least a modest advance, we are busy on both sides of the border raiding the first stage of schooling, to prevent the second from breaking down for sheer lack of teachers. Moreover, the dominance of class-teaching and the rigid time-table which so impoverishes the years from seven to twelve likewise makes them a poor preparation for the next stage. Until we can carry over that union of freedom and order which marks our best infant departments and make the primary years one unbroken experience in guided initiative and self-discipline, it is naïvely optimistic to hope that we can lift the controls at the beginning of secondary schooling and have the mass of children show responsibility and a dawning sense of community. That is the very point at which they are ceasing to be amenable and at peace with themselves, and are becoming for a season aggressive and senselessly destructive. It may be at best an act of faith that children, even if long habituated to a due measure of freedom, will in early adolescence react well to a very light rein: it is a near-certainty that children not so accustomed never will; and that has grave implications for the part of education, of which it still remains to speak.

Of further education two things must be said: first, that for our time and situation as a people, it is what matters most of all, and second, that its present extent and quality are deeply disappointing. It is all-important because even the most sanguine has never suggested that in the brief span of statutory schooling, however enlightened its aims and content, we could effect more than a good beginning of all that the complexity of modern life in a democracy requires of us. Only the unhurried, freely-sought education of adult life will repair the deficiencies. Again, while a transformed primary and secondary schooling would do much to foster the attitudes and dispositions which are the enduring basis of personal and civic worth, it could never in the nature of things impart to the half-formed creatures under its care the kind of knowledge on which the well-being of free communities rests—the late-won understanding of human nature and of the working of social and economic laws. Such knowledge, if it comes to ordinary folk at all, comes only with the maturing years.

And of the further education we need, we have pitiably little. Plenty of vocational training, and that is entirely as it should be. Plenty, too, of varied recreational provision, and that again is in the main good, even if very costly. But, by contrast, the kind of further education at serious levels which adds to our inner riches,

widens our vision, or awakens us to social responsibility, is still engaging only a fraction of our countrymen. In Scotland, with its five million people, the 1958 enrolments in general and cultural part-time courses of further education numbered only some 30,000, if we exclude physical training and country dancing. I have no reason to think the English figures would tell a very different story, and even if we add what other agencies are doing, it remains true that only a small minority of British adults are continuing their general education. Why? Because, whatever the schools have achieved, they have not so commended their wares that the customer keeps coming back, once he is free to stay away. I have no time to discuss in detail why our schools are failing so dismally by this supreme test of all, but I suggest two reasons. By clinging to a curriculum too heavily bookish in content and too rigorously intellectual in its demands, for all but the ablest few, we subject the many to a repeated experience of failure or at least of insufficiency, which goes far beyond anything that later life will normally bring them. Is it sentiment or softness, and not just common sense, to hold that the effect of such a classroom experience on ordinary bairns must be to dishearten, kill interest, and create a determination, whether conscious or not, to give education a wide berth, once school has been left behind? And the obverse of excessive demands on the intellectual side is comparative neglect just where the generality of children could do something and enjoy doing it, namely in the spheres of feeling, taste, and activity. Admittedly there has been improvement here in the past twenty years, but we still deny to music, drama, and the visual arts (surely the very stuff of further education for most men and women?) the sufficient place in school that would ensure their place once schooldays are past. Note, too, that this has a social as well as a personal significance, for the Scottish Advisory Council was right in claiming that 'it is through constant participation in such activities rather than by a severely intellectual process that the mass of human beings come to feel themselves part of a "culture" and sharers in a national inheritance'.

Our almost obdurate unwillingness to move towards a homelier and better-balanced schooling is the harder to understand because such a change is pressed upon us not merely by the sombre realities of our time but by the new thinking and discovery of half a century as well. From the side of psychology, two things may surely be taken as established now: first, that the gift of high intelligence is very sparingly bestowed and the range of innate ability far wider than our fathers dreamed; and second, that the place of the strictly rational and cognitive in human life is small compared with that filled by our strivings, feelings and imaginings. 'In the economy of human existence,' says Professor John Macmurray, 'the intellect is concerned only with the means of life, never with its ends', and he argues that 'the discipline of the imagination cannot be intellectual: it must be rooted in contemplation, in the life of the senses and the reflective activities that spring from it'.

So, too, the whole trend of recent philosophical and religious thinking seems, to my layman's understanding of it, to point in the same direction. For it is a trend away from rarefied idealism and Cartesian dualism towards an organic and unitary view of man as existent and person. Thinkers as different as Karl Heim and Maritain, Buber and Macmurray, have brought home to us the unique nature of the commerce of person with person, a relationship profoundly different from our observer-attitude to a world of things. Educationists like the late Sir Fred Clarke were quick to see how close this brings the good teacher's function to the artist's and how much the schools might do at their high and disinterested best to mediate true values to a generation in sore need of them.

In all I have said, there is neither misology nor any disparagement of scholarship and the things of the mind. Equally little is there unconcern about the maintenance of educational standards, if we mean by that, not fetish-worship of facts and their

acquisition, but the due exercising of youthful powers at whatever level they may be. Two simple lessons, however, we have still to learn; that, until we are content to accept children as they are, we shall go on losing the chance of developing the gifts they have, in our perverse determination to make them manifest powers which in fact they do not possess; and again, that in its aims and emphasis our education should reflect, as it does not at present, the inescapable truth that it is for most of us relatively easy to get a job and do it decently, but tragically hard to be good human beings in our communities, our homes, and our solitariness.

The threat of war, the fierceness of economic rivalry, and the lowly place and function a plutocratic society gives to education may make progress depressingly slow. What matters is that we should shake out of all complacency, see what is wrong, and as resources of men and money do become available use them to promote not just further instalments of comfort but the good life itself.

The late Baron Von Hügel in speaking of religion at its full depth dwelt always on its 'costingness'. So is it, I suspect, with true education. It will cost in the obvious sense that no people will get it for 3 per cent of the national income; but it will be costly too in rarer currencies—in the extent of sacrifice required of the best teachers and in the almost painful degree of their self-commitment to the needs of those whom they would serve.

If you ask where a nation in earnest about the reform of its schools must begin, the answer is: not with theories or techniques or material provision, important though all these are, but where unregenerate man usually has to begin—with a change of heart.

BALANCE IN BRITISH FARMING[1]

ADDRESS BY DR. H. G. SANDERS

PRESIDENT OF SECTION M

THE HONOUR of the Presidency of Section M, however unmerited, is specially welcome in a year when the Association returns to the place of its birth and meets at the centre of a great agricultural county. A Yorkshire student of agriculture once told me that he had no wish to continue his studies at another university since there was no type of farming outside the county that could not be found better practised in Yorkshire. He may have been a little prejudiced but he could point to hill, wold and warp farming, to the troubles of agriculture in industrial areas, to reclamations after the ghastly activities of the open-casters and, of course, to the long-established mixed farming of this great plain of York. During this Meeting we shall see something of the diversity of Yorkshire farming. Diversity is characteristic of British farming and it would be wrong to think that differences have arisen in any haphazard way. Farming systems have been proved and established by the long process of trial and error, that method which is so painful and so slow but which leads so inevitably to the right answer. The systems which have thus evolved have succeeded because they have a natural balance. To the scientist the word balance suggests weighing and no one would deny that modern farming calls ever more stridently for factual data, but for my present purposes I take an alternative definition of the word—equilibrium or, better still, harmony in design. This is characteristic of those farming systems which have survived. We are now living in an age when rapid changes come to farming. Science impinges more and more, and the grisly dictates of economics upset established practice. All this is right and proper but we ought to consider what might be lost if the balance in our farming disappeared and what might be gained if greater harmony could be introduced into the design of British Agriculture.

In very early times a farmer could only produce what the natural conditions of his land allowed, and since he was working only for subsistence he needed to take no notice of the world around him. We have moved far but there is no one moment in history from which the impact of the scientist and the economist can be dated. New knowledge came slowly at first but the pace quickened and it continues to accelerate; the world has never been in a settled condition but political turbulence seems continually to grow. Perhaps the lifetime of Section M can be distinguished from the years before. In 1912 knowledge of the so-called cognate sciences was, to our eyes, rudimentary, whilst the economic position, difficult it is true, had changed and was changing only slowly. Before 1912 farming found its own balance; since then it has had to cope with mechanisation, chemical fertilisers in quantity and, more recently, weird and wonderful chemicals of quite astonishing effectiveness. These are only some of the new aids that have come to farming and they have come in an era of major world upheavals. Looking back to Section M's birth we think, perhaps nostalgically, of a time when agriculture was securely poised and wonder whether it can have absorbed all that has happened since then without losing the balance it had achieved.

Notwithstanding all the reclamation work that has been done, in the last forty-seven years we have lost, in Great Britain, 10 per cent of our farmed land, that is, the land returned as under crops and grass. It is true that the returns show an increase of rather more than that in rough grazings, but we all know the inexactitude

[1] Address delivered to Section M (Agriculture) on Thursday, September 3, 1959, at the York Meeting of the British Association.

of that broad category, and I find it difficult to believe that we now use nearly 4 million acres more rough land for grazing than we did in 1912. Allowing for the decrease in area of farmed land, our corn acreage has increased by 16 per cent, with a notable switch from oats to barley, a switch which has occurred mainly in very recent years and which is likely to continue. Beans and peas for livestock have declined in relative acreage by nearly 40 per cent but, viewed rotationally, this is unimportant since it means a loss of only a quarter million acres which is compensated by the great expansion of peas for humans. If we use the word 'roots' in the usual loose way to include potatoes, sugar beet and other root and green crops there has been only a small relative decline in root acreage, some 8 per cent. Surprisingly, the comparison of the 1912 figures with those of today shows little change in proportion of grassland, though temporary has grown at the expense of permanent grass. In the same period our pig numbers have doubled and cattle increased by 40 per cent, whilst sheep numbers, after violent fluctuations, are about the same as they were at the beginning. We have seen the virtual disappearance of the horse and a vast increase in the head of poultry.

It would be very tedious to attempt a comparison of the amount of food available for livestock in 1912 and at the present time, and however careful the calculations the result would be vitiated by the wild guess that would have to be incorporated for the contribution of grassland. There is always the temptation in this sort of sum to ascribe an accuracy to the answer equal to that of the most accurate component figure but, of course, it is only as good as the worst, and in this case the worst estimate, that for grass, is very bad indeed. Very roughly, it appears that cereals now contribute an extra million tons of starch equivalent to livestock, to which must be added about three quarters of a million tons in increased imports. Although the horses did not eat the extra fodder roots grown in 1912, their requirements then about equalled the extra starch equivalent produced by the higher root acreage. As regards grazing animals, the number of 'cow equivalents' has increased roughly from 11 to 12 million, whilst the grass acreage (allowing for rough grazing) has declined from 23 to 21 million; thus the grass acres per cow equivalent have fallen from over 2 to $1\frac{3}{4}$. This suggests an improvement of barely 20 per cent in the offtake per acre from grassland but I believe that to be an underestimate. The Caine Committee quoted the global figures prepared by the Ministry for all animal foods, and on the basis of total livestock requirements deduced that the offtake per acre of grass has risen by 30 per cent since 1939.

There have, indeed, been big changes in British agriculture in the last half-century, but the June 4 Returns do not suggest that the balance previously established has been seriously disturbed. Even the structure as reflected in farm size has changed little—some 6 per cent more of our farms are now in the middle-size group (50–300 acres) with an equal reduction in the proportion of farms below 50 acres.

Left to herself Nature achieves a balance which ecologists refer to as a climax, but she reaches it by brutal methods and in her scheme of things there would be room for only a small fraction of the human population in the world today. Any sort of farming must upset that balance. As knowledge is gained, we are released more and more from Nature's restraints but we could go wrong and then she would have the last and ruthless word.

The basic necessity is to maintain the fertility of the land so that it can meet the ever-growing demand for higher output. No discussion of fertility should start without reference to those two fundamentals, liming and drainage. These basic operations release us from major natural limitations, and permit us to find a new balance favourable to our own ends. Our recent record in liming is fairly good. It is now uncommon to see otherwise good land at a miserably low level of production because of acidity, though such cases were frequently encountered between the

wars. To make good the slow loss of lime from the land and to encroach further on the remaining acid land it is desirable that we should apply some 7 million tons of lime (reckoned as calcium carbonate) annually. For some five years we have been at, or near to, this level. We can, indeed, verge on complacency over liming which, with the services we now have, is so easy for the farmer and which attracts a generous subsidy. The position with drainage is very different. Here we are living largely on the labours of our great-grandfathers, many of whose drains still run. But they will not last for ever, and it is no wonder that those laid in the middle of last century are slowly going out of commission. In many cases this is because of the inevitable silting-up which follows blocked outfalls. There can be no defence for the crime of letting a ditch fill in, and yet only about half the ditches cleared under grant since 1940 are being maintained. Figures for the number of drainage and ditching schemes completed year by year are fairly steady—they even show a slight rise—but a recent survey shows that about 50 per cent of our farmed land suffers to some degree from bad drainage. All are agreed that this sodden land is mainly caused by unkempt ditches, and the urgency of producing a practical and efficient machine for cleaning farm ditches is evident. The engineers are making some progress and I hope that we are about to see a much-needed advance in the drainage of our farm land.

The part that decaying organic matter plays in maintaining fertility has been furiously argued for years, and the arguments still continue. On the one hand we have the school of thought which attributes almost magical, and exclusive, merit to humus, and on the other we have the straw burners. It is perhaps as well that we have the former because the temptation of the highly mechanised corn grower to incendiarism is very severe. Collecting straw behind the combine adds very materially to the cost of harvesting; ploughing it in is troublesome and means immediate loss to fertility for the sake of a distant and uncertain gain. Fortunately the robbing of the land of what many regard as its due is not complete, because the cereal roots which the fire cannot reach, and such stubble as it spares, come to something like half of the vegetative part of the plant. But there is a loss, and the fear is that if this continues the land will suffer severely in fertility with a complete upset of the balance of the farming system.

We talk glibly about soil structure, which is something we can see and feel but something very difficult to measure; how good a measure the water-stable crumb is, I am unqualified to say. Of the value of crumb there can be no doubt; it provides the comfortable bed for the seed and permits percolation of water surplus to what we have come to call field capacity, and hence allows air to be drawn in for the benefit of roots and of beneficial organisms. All this is common ground, but the importance of the part that humus plays in crumb formation is a matter for dispute. That it makes the land easier to work is very clear to anyone who has ever done any gardening, but with plenty of power available it may be possible to dispense with this aid. For the weather will form crumb too. Thus the highly powered farmer on well-drained land may substitute timeliness in cultivation for humus, and he seems to get away with it. The difficulty of coming to firm conclusions on the subject lies in the slowness of changes in the organic matter content of soils. A dressing of muck raises the percentage very little, and the annual loss by oxidation is small and hence insidious. Disastrous effects of denying the land its due return may not appear for many years. I believe it took the Canadian farmers on the light prairie lands in areas of low rainfall forty years to produce the dust bowl. That was the ultimate tragedy, the complete breakdown of structure through the loss of humus, and one wonders whether the same thing will happen, and in how long, to the newly cultivated lands in Russia. Fortunately there are few, if any, areas in this country subject to the same risk but we could suffer lamentable loss of productive power in our soils.

The results of lowering the humus content of the land will certainly vary between

different soil types. This matter has been convincingly discussed by G. W. Cooke and H. V. Garner. Clay soils hold water and the crumb produced in them by weathering will persist long enough for one crop. Thus good cultivations, allowing plenty of time for the weather to act on the land, may suffice, and it is characteristic of straw-burning farmers that their cultivation is at a high level; quick disposal of the straw does in fact make it possible to get the land turned up as harvest proceeds. This is in conformity with the old saw that 'a good ploughing is worth a coat of muck'. At the other extreme, on sandy lands, drainage and aeration are naturally good, and it is in holding water that humus plays a vital part. I know of no experimental evidence whether, on such land, irrigation can take the place of humus, but it would seem to be a possibility. Many of us were surprised during the last war by the good crops obtainable from much poor light land that was reclaimed. The explanation presumably lay in the accumulation of organic matter on and in the soil built up during its years of waste. With the intermediate type of soils, consisting mainly of fine sand and silt, crumbs produced by cultivation when humus content is low are unstable and, as Dr. Pizer expresses it, the soil tends to flow, that is, to run together into a structureless mass. This impedes root penetration and hence plants suffer shortage of water and of nutrients. There seems to be a sort of threshold value for organic matter—1 to 2 per cent—below which this happens, so that it is not a case on such soils of the more humus the better, but rather that the content must be kept above the danger point.

There are apparently other perils attendant on low organic matter content with the light and medium soils, but little is known of them. The so-called Docking Disorder is a mysterious condition appearing in parts of Norfolk which mainly, but not exclusively, affects sugar beet. The plants just refuse to grow over irregular patches of a field, patches which are clearly and sharply defined so that one plant may be full grown and its neighbours in the row all diminutive. It may be that some organism is responsible, and suspects have been named, but no proof exists. All that is certain is that the condition appears when and only when the organic matter content of the soil is below the danger point.

We still have much to learn about the physical role of humus but it is clearly valuable, and in many soils and up to a certain minimum level it is probably indispensable if fertility is to be maintained. There is also the chemical value—the plant nutrients it releases in a slow and continuous manner, not forgetting the minor nutritional elements. We no longer look to decaying organic matter to supply the three major plant nutrients, although it makes some contribution. We have often heard of some sort of balance which should be kept between nitrogen, phosphate and potash, but I know of no evidence in farming of such a balance, save possibly in regard to quality in potatoes. It was shown thirty years ago that excess of nitrogen cannot be counteracted by generosity with the other two, and apparently the sole consideration should be that enough of each is present. The optimum economic dressing for nitrogen is always difficult to decide, but fortunately greater latitude is permissible with phosphate and potash, since excess beyond the crop's needs goes to a deposit account in the soil bank, on which someone will draw at a later date. The phosphate and potash residual plots at Rothamsted are a source of wonder to me; there is irrefutable evidence of the benefit of generous treatment even after more than fifty years since the applications stopped. Our farmers now spend around £90 million (less subsidy) each year on chemical fertilisers, and it is certain that the changes which farming has undergone have not lowered the plant nutrient content of the soil—indeed, the reverse must be true.

Soil fertility has another very important component—freedom from weeds, diseases and pests. Here methods have changed entirely, as we have substituted chemicals for the plentiful labour supply of earlier generations. The new herbicides

appeared in the nick of time, and their contribution is plain for all to see. Soil organisms appear fully competent to deal with any excess remaining in the land. But with fungicides and, more particularly, with insecticides, there is grave danger of upsetting the balance. To quote from Professor Wigglesworth's Presidential Address to Section D at Birmingham: 'It is indeed becoming increasingly evident that the use of more and more insecticides is creating insect problems as fast as it solves them', and again 'New machines and new chemicals are developed and we are carried from crisis to crisis, always hoping that the newest chemical and the newest technique will provide the final answer'. Here indeed is a way in which we could rapidly lose balance in our farming, and if we choose easy, blunderbuss methods we may well get into trouble. The work at the Vegetable Research Station, Wellesbourne, on cabbage root fly gives food for serious thought. In normal circumstances predators on the fly consume over 90 per cent of its eggs; when these ground beetles are kept off a plot by bands of straw soaked in insecticide, loss of plant from the fly is doubled. To treat all land with insecticides may well be disastrous, since it is more likely to kill the predators than the pest. There is also the 'resistance movement' about which Scott Watson has written, pointing out that an insecticidal spray kills off susceptible types and leaves the resistant ones, which thereafter, having no competition, multiply exceedingly. Each year some quarter of a million acres of land, mainly destined for potatoes, are dressed with compound fertiliser pepped up with a powerful insecticide, even though the wireworm population is only seriously high on a small fraction of it. This sort of blanket protection of a crop is full of menace, and I feel that we must soon forsake it for more specific and localised methods. Thus I would not think that the same strictures apply to the protection of cereals by seed dressings or of cabbage plants by ringing each plant with insecticide. It is well that entomologists are keeping a close watch on this matter; we may easily put a foot wrong but I do not think we shall rush headlong to destruction.

The traditional way of maintaining balance in farming was the rotation, well exemplified by the stately Norfolk four-course, which certainly had harmony in design in full measure. New discoveries have released us from what some would call the thraldom of rotation, but the onus is now on us to avoid any dreadful discords. To get the maximum gain from our freedom we have not only to maintain an overall balance but also to keep in step within the system. Thus new cereal varieties and heavier manuring must obviously go together. The same is true for cultivations. In mechanisation we must think not only of the efficiency of a particular implement or method but also how it will fit into a series of operations. For instance, it is possible to grow a crop of sugar beet without any hand work at all, but the whole thing has to be planned from start to finish. The original ploughing must leave no open furrows; subsequent working must aim for the traditional fine, firm and mellow seedbed together with a surface like a billiard table; with pre-emergent spraying and rubbed or monogerm seed sown through a spacing drill it should then be possible to do good work with a down-the-row thinner and leave a plant sufficiently even in size and spacing for a complete harvester to do a good job. The point is that each little bit of mechanisation may be some help, but for the full gain the whole lot are wanted. Much investigation has gone to the mechanisation of the sugar beet crop, which is now far advanced; it should not be difficult to apply the same methods to other root crops. The swede turnip has performed nobly in the past and many farmers in the wetter districts still hold it in high regard, for there it can produce high yields of starch equivalent. Its labour demand is defeating it, but some people are finding it possible to apply modern methods used in growing sugar beet to it, even in such unpromising situations as steep and stony land. The mechanisation of potato growing is, at the moment, lopsided. There are a number of satisfactory planters but as yet no really efficient harvester for all sorts of

conditions, and if a planter is used to save casual labour it may be impossible to get that same labour for picking. Good cultivations have never been easy. Tractor power brought the chance to get ahead with the work so that on well-weathered land we could get blundering by with discs. Artistry has now gone from cultivation, but forethought must take its place to plan the whole sequence of operations so that it is in balance.

The ley has replaced roots as the pivotal crop of the rotation, the point on which the sequence is balance. Compared to 1912 we now have 5 million acres less land in permanent grass but we still have 12 million acres, a fact which incurs Dr. William Davies's severe censure. Where rainfall is high and long leys easy to establish, their position has been secure for many years. Where rainfall is lower and undependable short leys have been the rule, alternate husbandry has been slowly adopted and cannot yet be regarded as secure in farming systems. Better seed, better manuring and better techniques have made the establishment of long leys reasonably reliable, but in a dry year production from any sort of grassland is poor, whilst there is always the alluring alternative of profitable cash crops. Professor Duckham and his people at Reading are showing what tremendous possibilities there are in the ley with irrigation, but that can only be practised on those areas where free supplies of water are available. It is now accepted doctrine that leys are more productive than old pasture. This is the sort of thing that is very difficult to prove, but a whole body of evidence has accumulated which shows it to be the general rule. There are possible exceptions. The very best of our permanent pastures may be incapable of improvement by ploughing, cropping and reseeding, but they constitute only a minute fraction of our old grass. There may also be some doubt in certain awkward farming situations, and Mr. Mudd in East Lancashire has demonstrated the possibilities of improving poor grass by good management, improving it as quickly and to the same extent as by ploughing and reseeding. But these are exceptions. Only by starting afresh can we get a ley consisting of newer and better strains, such as will respond to the generous manuring which ought to be the rule. All this is widely accepted, but what is not so clear is the part the ley can best play in the balance of a farming system. Where the system must perforce rest practically exclusively on the sale of livestock and their products, the main considerations must be the productivity of the ley itself and how that falls off with age. Even under high management a decline sets in at about the third or fourth year, which the late Dr. Bates ascribed to the build up of a sub-surface mat. But this same sub-surface mat is very valuable when it is broken up and distributed through the soil by cultivation. On the one hand, as the years go on, the ley as such is declining in value; on the other, it is building up that for which succeeding crops will be grateful. Dr. Bates's figures showed a continuing rise in the dry weight of the mat up to seven years, whilst work at Jealott's Hill suggests that it takes at least sixty years to get back to the condition of an old permanent pasture. Where it is the ley itself which is of the first importance, deciding on its length of life is fairly easy. Where the ley is primarily a means to the end of better cash crops, the decision is more difficult. Land is begrudged for grass, and leys may be as short as two years, even though that means sacrificing the ploughing-up subsidy. The flexibility of the ley makes it very suitable for the point of balance of a farming system.

Outstanding farmers have brilliantly demonstrated in recent years how great is the contribution which leys can make. Cattle can be fattened on land which had never been thought of as in the supreme, almost mystical, category of fattening land, and with cows reliance can be on grass, even exclusively, for seven months of the year. High-level grazing calls for quick cuts for conservation after short spells of growth, and hence silage not only fits in well with good grazing control but is almost an essential part of it. Ley farming at its highest thus contributes nobly to

winter feeding and can save much expenditure on concentrates. But there is a great gap in our knowledge here and one which it is urgent to fill. There is great variation in the quality of the silage made, as also of the hay, and methods are known by which high quality material can be obtained. But these methods are expensive, and figures are available to show the added cost of really high quality silage compared to that of poorer material cheaply ensiled, as there are for tripod or barn dried hay compared to the ordinary run of pick-up baled hay. What is not known is the increased value of the good silage or hay—the extra milk that can be got from each ton and the amount of economy in cake bills which may result. Exhortation is perched, as it were, on one leg and that the troublesome one of increased effort and expense; it cannot be really effective until the balance is restored and the other leg, that of the reward to follow, is firmly planted.

Self-sufficiency is a term to which we have become throughly accustomed and, of course, it implies a well-balanced farming system. The greater the contribution from home-grown supplies the smaller will be the bill for purchased concentrates, but it may involve extra labour and it could mean lowered yields from livestock. The principles of nutrition on the basis of which we have worked for a generation are now under question, and possibly with more knowledge of them and with high quality roughages we shall be able to do a good deal better. We have always talked of balanced rations but, just as with manuring crops, there does not seem to be any magical proportion between nutrients. It appears more likely that there are various minima to be met and a number of workers in the last twenty years have produced evidence that the minimum for protein is lower than we have been led to believe. Since protein is expensive the minimum is presumably the optimum. In regard to starch equivalent there is more flexibility and rigid minima scarcely apply. In any case, Blaxter, by an ingenious use of a statistical parameter, has shown that, for practical application, the accepted standard allowances are 10 per cent too low. It is only in recent years that there has grown a wide acceptance of the idea of diminishing returns in animal feeding, the idea that each succeeding increment in return requires more input than the preceding one. This leads us to a nice balancing of two contrary effects. The more units an animal produces the less the impact of the animal's maintenance on each, but as production increases each unit is more costly in itself. Thus the maximum possible production is not necessarily the most economic. Mansfield and Trehane, between the wars, showed this to be true with bacon pigs, and there was the added fact that restricted feeding avoided excessive fat in the carcase, a point of great importance nowadays with all meat-producing animals. Most farmers take the view that with milking cows a reasonably high, rather than a stupendous, yield should be the aim and are well satisfied around the thousand-gallon mark as a herd average. The diminishing returns principle accords well with greater reliance on roughages, always insisting on roughages of high quality. The accepted principle is to provide roughages for maintenance and one, possibly two, gallons of milk with some 4 lb. of concentrates for every gallon over that. A system now being advocated is to allow about 2 lb. of concentrates per gallon but to allow it for every gallon the cow yields, leaving it to her to make good her requirements on hay, silage and so on. The low yielder may gain a little in the amount of concentrates she gets but the high yielder loses unless she is offered roughages of really high quality. But presumably there will be wide differences between individual cows in capacity to consume enough. Which leads to speculation whether we have the right type of cow for the job and, if not, whether we can breed such a cow. A more immediate prospect is to try and train our cows by feeding more bulk during their heifer years; there has for a long time been argument whether this training works and current experiments may shed light on the question. All this seems to me to be very important because any raising of the level of self-sufficiency must make for better balance in our farming.

Furthermore, it is one of those happy conjunctions where Government policy accords precisely with the interests of the individual farmer.

For the greatest good we want balance not only on each farm but for our farming as a whole. There is, of course, much interchange from area to area, and I feel that this should be fostered, though I am not at all clear whether this should be done by government or by farmers' organisations. One well-known instance is the contribution which the hills make to lowland farming. Davidson and Wibberley have made a study of this. They concluded that if hill farming did not exist in this country our mutton and lamb production would suffer to the extent of 60 per cent, though theoretically some of this might possibly be retrieved if the movable fodder released on the hills were fed to sheep on lowland farms. By contrast, cattle production would only suffer a diminution of 10 per cent. The movement of store cattle and sheep from the hills to the lowlands and from the west of the country to the east has grown up in a rather haphazard way, and I doubt whether anyone would claim that it is either efficient or convenient. Some farmers at the receiving end, men who have an eye for an animal and who delight in personal dealings with fellow farmers, work a round among generally small farms in the breeding areas, buying a bunch here and a bunch there to meet their needs. This may be a form of holiday for them, though a very expensive one, but it is a great time-consumer and impossible for the great majority of farmers who want to buy stores. There are the great sheep sales in the lowlands of Scotland and near the Welsh Border where the English farmer can get his requirements in the free competition of the auction. These sales deal with vast numbers of sheep with the utmost despatch, and it may be that the system is the best that human intelligence can devise. It is interesting to note that similar methods have been adopted in recent years by the breeders of Hereford cattle in Brecon and Radnor, six sales being organised each autumn; last year 4,500 cattle were sold to thirty English counties. This distribution is very different from that of the Irish cattle which make their way in great number to Northumberland, Yorkshire, Lincolnshire, Norfolk and the summer fattening counties of Leicester and Northampton. This trade is not organised at all on this side of the water except that certain markets have established themselves as main centres of distribution.

It cannot be claimed that the south-easterly migration of store cattle and sheep is efficiently organised. Many are indeed collected from widely scattered breeding areas and put on offer at accessible centres, but many others zigzag their way across the country in an aimless sort of way. There is another movement which is in the contrary direction—that of feeding grain from the corn-growing areas to the west where the large numbers of livestock exist. This has no organisation at all, and its efficiency depends entirely on the business ability of individual merchants. A certain amount of channelling of the flow has been stimulated in the last twelve months by specially reduced rail rates for specified movement of over seventy miles, and we must hope that this is only a beginning, for, surely, large consignments moved in bulk could be transported very economically. Is it too much to hope that similar methods may be developed for straw so that this bulky material can be moved from the areas where some despise it to areas where it commands a high price? There are certainly very considerable difficulties in solving what the military people would call these logistical problems of our agriculture, but really efficient organisation of these east–west and west–east movements would do much to maintain the balance in the country's farming.

Britain has a proud record in the development of breeds of livestock. The pedigree idea of breeding within a restricted population of animals with defined similarities has done much, but further progress is difficult, though something may be expected from a more general reliance on progeny testing. Not all farmers are interested in pedigree breeding and many have not the special ability needed to

make a success of it. What these men want is a useful commercial animal that will do well in, perhaps, very moderate conditions. Evidence continues to accumulate that for this a cross-bred animal is often the best, and we explain its superiority as a manifestation of hybrid vigour. The great American success with hybrid maize has involved the development of a number of inbred lines, many of which have to be discarded because they do not 'nick' when it comes to crossing, and when we ponder on this we are apt to be discouraged over the possibilities of applying these methods to livestock breeding. There is much evidence, however, that the cross-bred from non-inbred parents gains in vigour and the ordinary farmer might be well advised to exploit this gain. With poultry this is, in fact, being done in a big way; I gather that preliminary inbreeding is not common in the production of commercial birds either for laying or for broiler production. In the last few years we have seen a revolution in the poultry industry, the breeding of commercial birds having become a specialised job which is getting more and more the business of a few people who produce them by the million—and these commercial birds are cross-breds. Poultry are cheap and quick in their generations, two characters in which geneticists delight, but it is not beyond the bounds of thought that we might move some distance in the same direction with other farm livestock. We know that, with them also, cross-breds have special vigour. It would be a great help if we could find some guide in our search for strains that will 'nick'—perhaps more knowledge of blood groups may give the answer, though this rather smacks of wishful thinking.

With cattle, sheep and pigs we are never likely to leave the breeding part of the business to a few individuals, but it may be that we shall develop a sort of three-tier structure. At the top would be the pedigree breeders with aims much as at present but with methods firmly based on progeny testing. A second tier would also have pedigree animals but they would do the crossing to provide offspring for the third tier whose job would be the commercial exploitation of the cross-breds. In sheep we already have this type of structure pretty well developed. The merits of the Scotch Halfbred ewe have long been established; the Welsh Halfbred has come to prominence more recently and the only complaint heard about it is the same as against the Scotch, its price. The development of this cross-breeding has, of course, been due primarily to the requirement of hardiness in the ewe for the hills and to the success of the Border Leicester for crossing with such ewes. There is no dispute as to the high value of either of these crossbreds for crossing with Down breeds on lowland farms. There seems to me little to be said for further and often indiscriminate crossing with other breeds except on the score of cheapness in replenishing lowland flocks; whether it is cheap in the long run is open to considerable doubt, for the valuable properties of the first cross are lost and the nondescript sheep produced will never fit well into any improved carcass grading system. There is no need to labour the point; we have the rudiments of a three-tier system with sheep and I need only mention the success of first-cross sows and cows. To exploit hybrid vigour in other forms of livestock may be more difficult than in poultry, but the gain in efficiency may be enough to justify the effort.

A planned system for the breeding of our livestock would go some way to meet the ordinary farmer's growing problem of how to keep up to date. Alert-minded men who have grown up as farmers during the last two decades of rapid scientific advance may have managed to keep abreast of progress, but the pace quickens. Even with a sound educational introduction to modern farming it is going to get more and more difficult to be expert in all its varied facets. One solution is for the individual farmer to specialise and there is, indeed, some evidence of movement in that direction. But the ultimate aim is surely not monoculture. Simplification will be imperative but this need not necessarily mean drastic reduction in the number of commodities a farmer sells; some of the steps in several lines of production can

be hived off. Contractors have relieved many farmers of the job of applying herbicides and also of the need to know the latest and best chemical to use, how to use it and in what formulation and dosage. As standards are raised for seed, its production and guarantee of dependability become more and more the task of specialist farmers and seedsmen. It is not a big step to the point where general farmers with no great livestock interest, no wish for the detailed recording entailed in successful breeding and no great amount of capital, look to others to produce their livestock. This would keep balance in the country's agriculture and would enable the ordinary man to be expert in several lines of production and so not lose the balance of his own farming. In farming we do not in general go to extremes. I think we can gain much by travelling some distance along this road, but do not think we shall reach the 'vertical integration' now developing in broiler production, which few of us would regard as an alluring prospect.

There are many other facets of this matter of balance. I have said nothing of the supremely important balance between summer and winter keep on the hills, between species in a grass field or between the numbers of cattle and sheep for proper control of grazing. All these contribute to the harmony in design which is characteristic of a high level of husbandry. Our land is now producing more than it has ever done before and if the need arises we can, with the help of science, easily raise the level far higher. But as we replace the ideals of husbandry with the controls which science provides, we must keep an ever watchful eye on the danger that our farming might lose its balance.